Geol Survey

HANNIBAL BRIDGE WETLAND COMPENSATION SITE: FINAL HYDROGEOLOGIC CHARACTERIZATION REPORT

Hannibal Bridge, U.S. Route 36
East Hannibal, Pike County, Illinois
(Federal Aid Project 36-037-73)

Nancy L. Rorick
James J. Miner
Paul E. Hilchen
Coastal and Wetlands Geology Unit

Illinois Department of Natural Resources
ILLINOIS STATE GEOLOGICAL SURVEY
615 East Peabody Drive
Champaign, IL 61820-6964

Submitted Under Contract No. AE89005 to
Illinois Department of Transportation
Bureau of Design and Environment, Wetlands Unit
2300 South Dirksen Parkway
Springfield, IL 62764

March 19, 1998
Illinois State Geological Survey
Open File Series 1998-2

HANNIBAL BRIDGE WETLAND COMPENSATION SITE: FINAL HYDROGEOLOGIC CHARACTERIZATION REPORT

Hannibal Bridge, U.S. Route 36
East Hannibal, Pike County, Illinois
(Federal Aid Project 36-037-73)

Nancy L. Rorick
James J. Miner
Paul E. Hilchen
Coastal and Wetlands Geology Unit

Illinois Department of Natural Resources
ILLINOIS STATE GEOLOGICAL SURVEY
615 East Peabody Drive
Champaign, IL 61820-6964

Submitted Under Contract No. AE89005 to
Illinois Department of Transportation
Bureau of Design and Environment, Wetlands Unit
2300 South Dirksen Parkway
Springfield, IL 62764

March 19, 1998
Illinois State Geological Survey
Open File Series 1998-2

CONTENTS

FIGURES

TABLES

INTRODUCTION

This report has been prepared by the Illinois State Geological Survey (ISGS) for the Illinois Department of Transportation (IDOT) to provide a hydrogeologic characterization of the proposed Hannibal Bridge wetland compensation site and to describe planned monitoring. Summaries of ground- and surface-water levels, collected after construction, will be submitted as required by IDOT. Monitoring will continue for five years after construction, unless otherwise directed.

The wetland compensation site for construction of the U.S. 36 bridge over the Mississippi River is a farm field (the Campbell property) near East Hannibal, Illinois (figure 1). The ISGS evaluated the hydrogeology of this site. The site is 0.2 km (0.15 miles) north of U.S. 36 and 150 m (500 ft) northeast of the Sny Levee District levee (figure 1) and is approximately 7.0 hectares (17.3 acres) in area. Within the site is a 4.87-hectare (12.04-acre) existing wetland (figure 2). Bordering the site on the south and east sides, and a portion of the north side is Bird Slough, a tributary of The Sny.

Included in this report is a hydrogeological characterization of an additional parcel in Shepherd (figure 1) located between U.S. 36 and the proposed bridge alignment (requested May 3, 1994), and a discussion of the proposed wetland design. The parcel in Shepherd covers approximately 1.12 hectares (2.8 acres).

The objectives of this study are to (1) provide IDOT a hydrogeologic characterization of the project area based on geologic borings and water-level monitoring, and (2) make recommendations concerning wetland construction. To accomplish these tasks, the ISGS has drilled boreholes to determined site stratigraphy, installed monitoring wells on site to monitor ground-water levels, and placed stage gages in the existing wetland and Bird Slough to monitor surface-water levels.

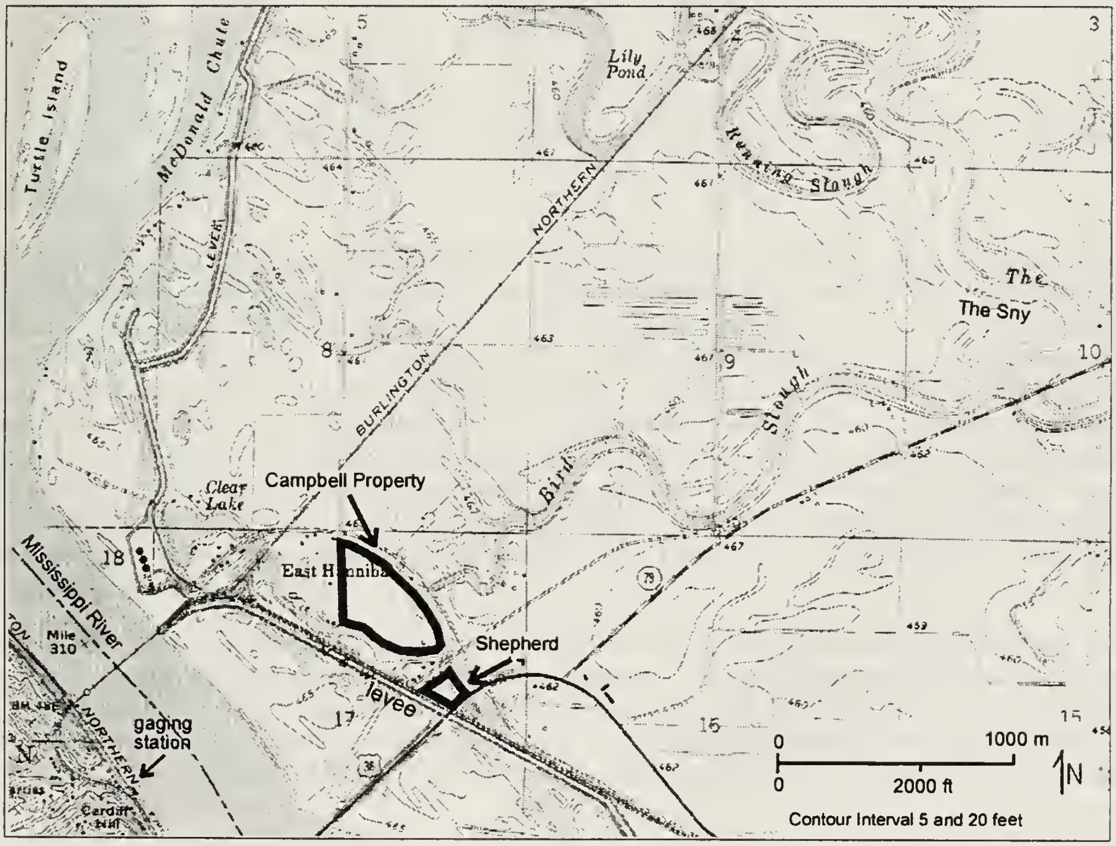


Figure 1 Project location map from the Hannibal East Quadrangle (USGS 1971).

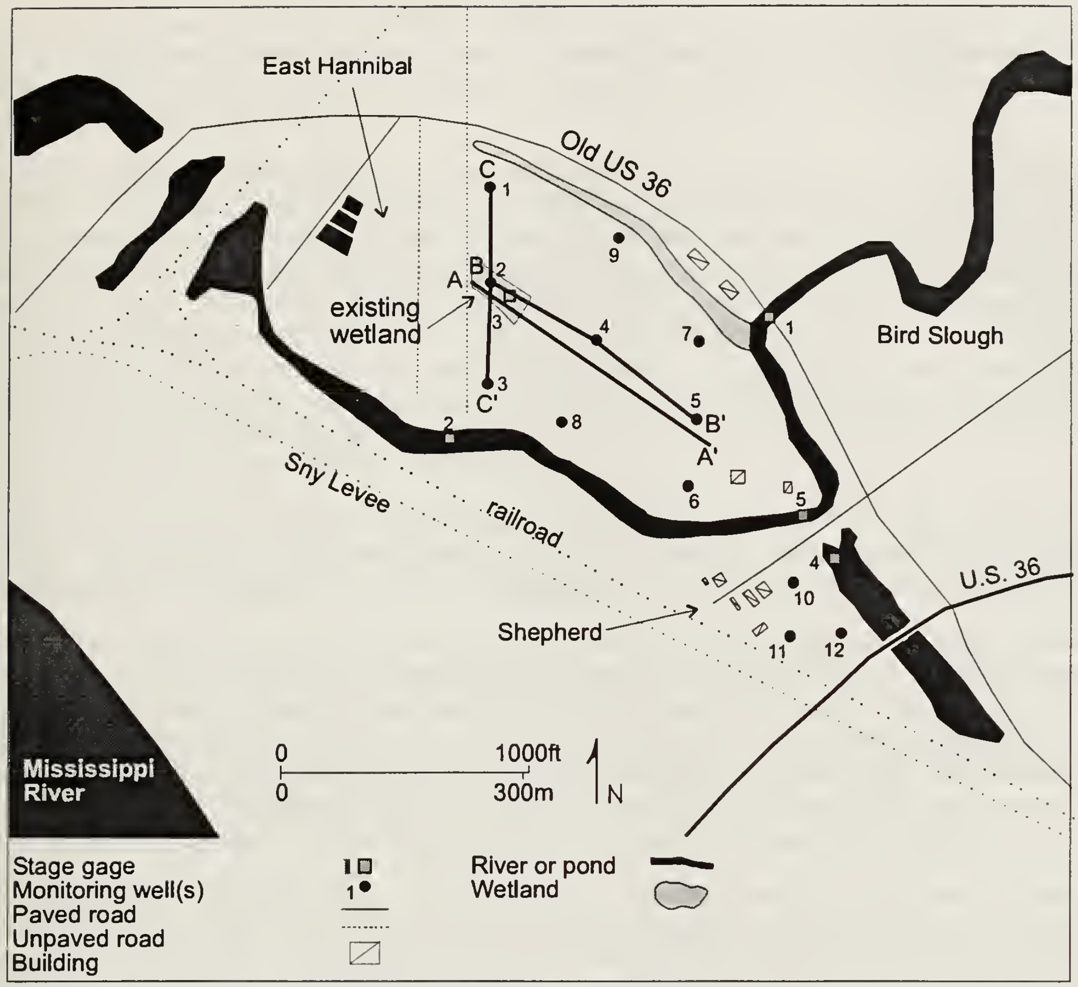


Figure 2 Well location map showing lines of the cross sections.

METHODS

The ISGS drilled borings to determine the site stratigraphy, and installed monitoring wells and stage gages to monitor water levels. The logs of borings are presented in Appendix A and the water-level data are presented in Appendices B and C. In October 1992, workers installed monitoring wells 1a through 6a at well locations 1 through 6 on the Campbell property (figure 2). The boreholes were drilled with a 150-mm- (6-in.-) diameter, hollow-stem auger with a continuous sampler. The well (constructed with 25-mm (1-inch) schedule-40 PVC pipe and 0.25-mm (0.01-inch) slotted well screen) was lowered down the auger stem. The annulus surrounding the well screen was packed with sand (0.2 to 0.4 mm Colorado brand) as the augers were withdrawn from the borehole, and the borehole was then sealed to land surface with bentonite chips. Well construction data are shown in Appendix D. These wells were developed in November 1992 by pumping them with a peristaltic pump until the water ran clear.

In February 1993, monitoring wells 7a and 8a were installed at well locations 7 and 8 (figure 2) to augment information gained from the first set of boreholes. The ISGS excavated these boreholes by pounding 76-mm (3-in.) diameter aluminum irrigation pipes into the ground, and then removing pipe and core from the borehole with a jack. The well screen and casing (PVC pipe) were next inserted into the borehole and sand (0.2 to 0.4 mm Colorado brand) was packed around the well

screen. Well 7a was constructed from 50-mm (2-in.) diameter schedule-40 PVC pipe and 0.25-mm (0.01-in.) slotted well screen, and well 8a was constructed with a 25-mm (1-in.) schedule-40 PVC pipe and 0.25-mm (0.01-in.) slotted well screen. Above the sand pack, the borehole was sealed to land surface with bentonite chips.

On April 20, 1994, the ISGS replaced well 1a (destroyed during the 1993 flood) with well R1a. On May 17 and 18, 1994 the ISGS installed twelve additional wells on the Campbell property (well 9a at well location 9; wells 1b through 5b and 7b through 9b at well locations 1 through 5 and 7 through 9, and wells 1c, 3c, and 4c at well locations 1, 3, and 4). On the Shepherd site, the ISGS installed five wells (10a, 10b, 11, 12a, and 12b at well locations 10, 11, and 12). All of these boreholes were drilled by hand with a 50-mm- (2-inch-) diameter bucket auger and constructed from 25-mm (1-in.) schedule-40 PVC pipe and 0.25-mm (0.01- in.) slotted well screens. In each of the wells, the annulus surrounding the well screen was packed with 0.2 to 0.4 mm (10-mesh) sand to approximately 0.3 to 0.6 m (1 to 2 ft) above the top of the well screen, and then sealed to land surface with bentonite chips. The wells installed by hand were not developed.

Elevations of monitoring wells and stage gages were determined to third-order accuracy using a Sokkia B-1 automatic level and a fiberglass extending rod. The wells and gages were surveyed from a temporary benchmark established by IDOT (based on the 1929 National Geodetic Vertical Datum).

On May 23 through 26, 1994 the ISGS mapped the upper 2 to 3 m (6.6 to 9.8 ft) of surficial sediments on 50 by 50 m (164 by 164 ft) grids established over both the Campbell property and the Shepherd site. ISGS personnel probed the sediments at each grid point and recorded the depths of the different units. Where the stratigraphy changed between two grid points, another boring was made midway between. An IDOT District 6 survey crew surveyed the land-surface elevation at each grid point. From this, IDOT District 6 personnel developed contour maps showing land-surface elevation (figure 3), and the elevations and thicknesses of geologic units in the sampled interval.

The water levels in the monitoring wells have been monitored since the wells were installed in November 1992 and May 1994. Tables of water-level elevations and depth below land surface are presented in Appendix C. Stage information for the Mississippi River was obtained from the U.S. Army Corps of Engineers (USCOE), Rock Island District for a gage on the west bank of the Mississippi River at the Hannibal Water Works (figure 1). From July 25, 1993 through October 12, 1993, the site was inaccessible due to the 1993 Mississippi River flood.

GEOLOGY

Regional Setting

Topography

The portion of the Mississippi River flood plain in the project vicinity between the Sny Island levee and The Sny is generally lower in elevation than the stage of the Mississippi River (United States Geological Survey (USGS) 1971). In 1992, for example, the average river-stage elevation of 140.63 m (461.40 ft) was 1.9 m (6.3 ft) higher than the lowest part of the flood plain at an elevation 138.7 m (455 ft). The land-surface elevations on the Campbell property, measured on the IDOT/ISGS survey grid, range from 139.36 to 140.82 m (457.22 to 462.01 ft) (figure 3).

The USCOE zero-gage elevation at Hannibal is referenced to the National Geodetic Vertical Datum (NGVD) of 1912. All Mississippi River gage data used in this report have been corrected to the 1929 NGVD.

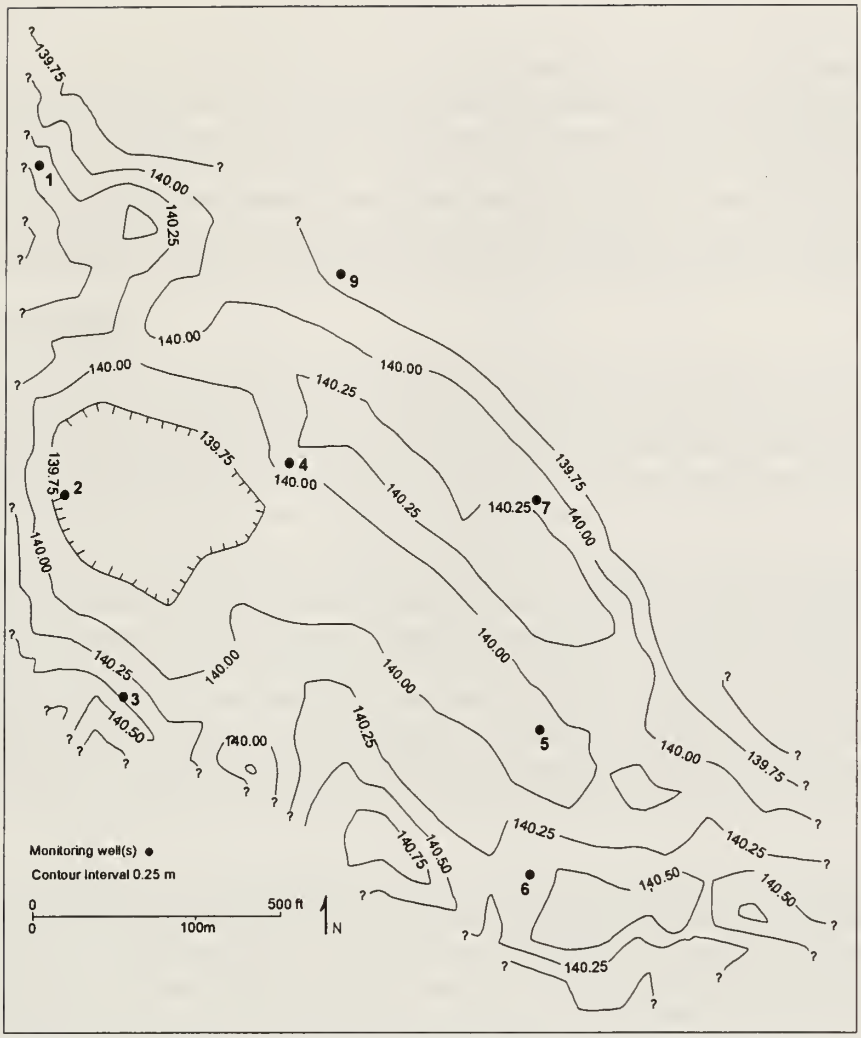


Figure 3 Land surface elevation map prepared by IDOT. The elevations are referenced to NGVD 1929.

Bedrock

Bedrock below the study area consists of shale and limestone of the Maquoketa Shale (Ordovician) (Willman *et al.*1967 and Willman *et al.* 1975).

Quaternary Sediments

Approximately 30 m (100 ft) of Quaternary sediments overlie bedrock (Piskin and Bergstrom 1975, ISGS well-log library). Sand and gravel of the Mackinaw Member of the Henry Formation (Wisconsinan Stage) (Berg and Kempton 1988, Lineback 1979, Willman and Frye 1970) is overlain by the Cahokia Alluvium, a post-glacial deposit of sand and silt (Willman and Frye 1970). Well logs and bridge borings (from the ISGS Geologic Records Unit and IDOT) cover an area extending from the site to 3 km (1.9 miles) to the northeast, 2 km (1.2 miles) to the north, and 2 km (1.2) to the southeast. These logs show that the area is covered by a layer of clays and silts that ranges in thickness from 2.1 (7 ft) to 5.2 m (17 ft). These fine-grained deposits overlie coarse-grained deposits of sand and gravel. None of the borings, including the deepest one drilled to 21 meters (69 ft), encountered bedrock.

Soils

Soil maps of Pike County (United States Department of Agriculture (USDA), unpublished) show five different soil types at the field site, four of them are listed as hydric on either the county (USDA 1992) or national (USDA 1991) hydric soils lists. The hydric soils are the Shafton silty clay loam at the northeast edge of the field site (county list), the Ambraw silt loam in the center of the field site (national and county lists), the Ceresco loam at the western edge of the field site (county list), the Coffeen loam in central and eastern portions of the field site (county list). The Sparta loamy fine sand in the southeast corner of the site is not listed as a hydric soil (national and county lists).

Site Characterization

The surficial sediments on the Campbell property can be divided into a lower unit of sand, a middle unit of clayey silt, and an upper unit of sand. Cross sections (B-B' and C-C'), show the three units (Appendix A, Part 2). Figure 4 is a cross section (A-A') of the Campbell site based on data gathered from mapping the surficial sediments on a 50 x 50 m grid. The cross section shows the variability in thickness and elevation of the lower, middle and upper units.

The lower unit is a well-sorted and well-rounded, medium to fine-grained sand composed primarily of quartz with some potassium feldspar and magnetite. Well and boring records (supplied by ISGS and IDOT) and the depth to bedrock map (Piskin and Bergstrom 1975) suggest that the lower unit extends laterally across much of the flood plain, is approximately 30 m (98 ft) thick under the site, and directly overlies bedrock. The field site is on the inside of a large meander bend of the Mississippi River suggesting that the upper portion of the lower unit may be a lateral accretion deposit. A joint survey, conducted by the ISGS and IDOT, found that the elevation of the top of the lower sand unit ranges from 138.0 to 139.8 m (452.8 to 458.7 ft). Figure 5 shows the elevation of the top of the lower sand unit.

The middle unit consists of fine-grained deposits of silty clay to clayey silt. Commonly the unit is thinly bedded with thin (less than 5 mm or 0.2 in. thick), alternating laminae of sand and clayey silt. The sand laminae are composed of fine, well-sorted and rounded sand. The texture of the clayey-silt laminae ranges from silty clay to clayey silt with some sand. The middle unit extends over most of the Campbell property. The unit, where present, ranges in known thickness from 0.18 to 1.68 m (0.33 to 5.81 ft), and has an average thickness of 0.69 m (2.3 ft).

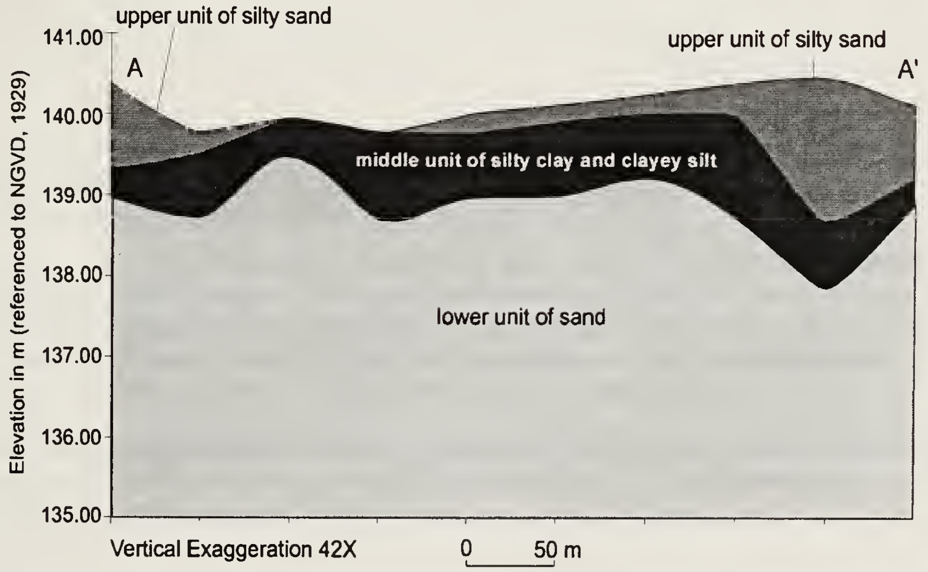


Figure 4 Cross section A-A' based on data gathered from mapping the surficial sediments on a 50 by 50 m grid. Line of cross section shown on figure 2.

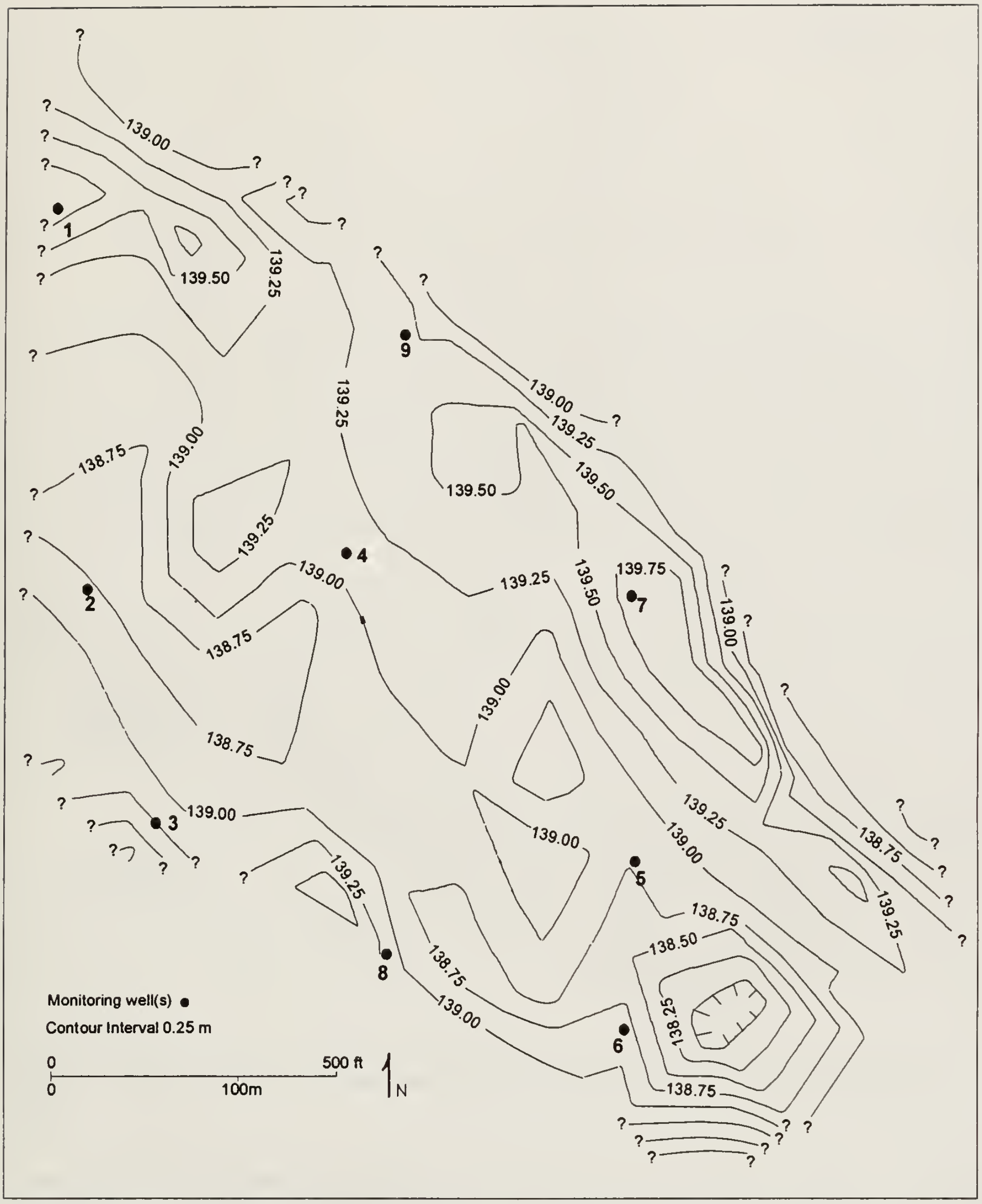


Figure 5 Elevation of the upper surface of the lower unit of sand (map prepared by IDOT). Elevations are referenced to the NGVD 1929.

The upper unit is a surface deposit of fine sand to silty sand, and is not continuous across the Campbell property. Where present, the unit ranges in thickness from 0.10 to 1.77 m (0.33 to 5.81 ft). The isopach map (figure 6), from a joint survey conducted by the ISGS and IDOT, shows the combined thickness of the upper and middle units. The combined thickness of these two units ranges from 0 to 2.60 m (0 to 8.5 ft) with an average thickness of 0.9 m (2.95 ft).

The minimum recorded water-level elevation for Bird Slough at stage gage 2 is lower than the bottom of the middle unit on the site, indicating that the channel of Bird Slough penetrates through the middle unit. The depth of Bird Slough was not measured.

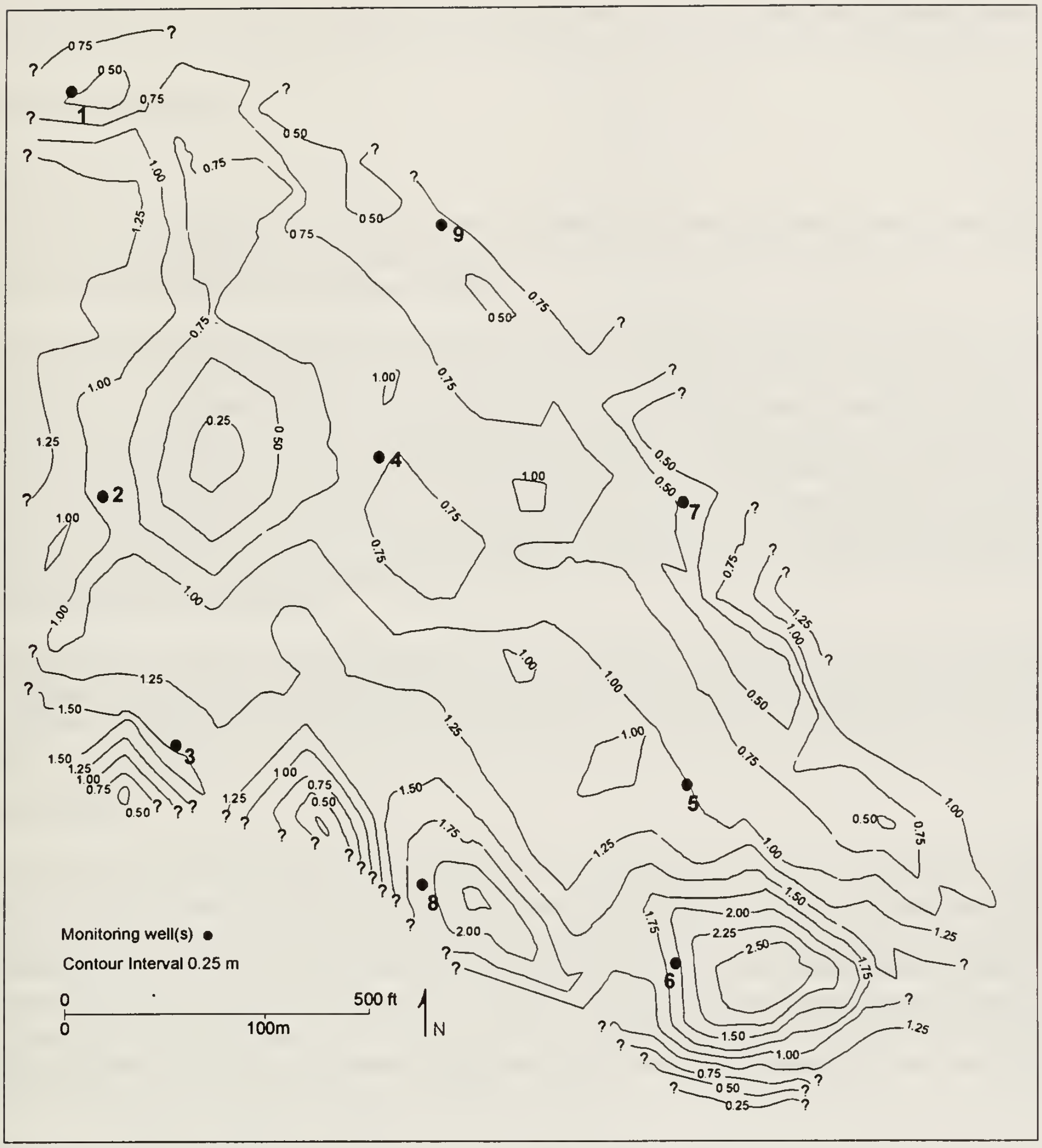


Figure 6 Isopach map of the combined thickness of the middle and upper units (prepared by IDOT).

At the Shepherd site, the upper unit ranges in thickness from 0 to 0.73 m (0 to 2.40 ft). The middle unit, composed of silty clay, silty sand and clayey silt, exists at all well locations and ranges in thickness from 0.35 to 2.06 m (1.15 to 6.76 ft).

Background

The sand and gravel sediments underlying the field site and filling the Mississippi River valley compose a large aquifer. Regionally, water in the aquifer flows in a downstream direction parallel to the Mississippi River (Larkin and Sharp 1992). Adjacent to the river, the water level in the aquifer fluctuates in response to stage changes in the Mississippi River (Meyer and Turcan 1955). According to a local resident, many citizens obtain water from this aquifer with shallow wells constructed by driving a screened metal pipe (a sand point) into the ground.

The Mississippi River is separated from its flood plain by the Sny Levee (figure 1). The flood plain east of the Sny Levee is drained by The Sny, which flows southeast parallel to the Mississippi River.

Numerous small streams and drainage ditches originate near the levee and flow eastward toward The Sny, which is about 1.5 m (5 ft) lower in elevation than the Mississippi River (USGS 1971).

Site Characterization

Surface Water

Local surficial drainage (east of the Sny Levee) is toward the east and southeast, away from the Mississippi River (USGS 1971). East Hannibal and the Campbell property are drained by Bird Slough, a tributary of The Sny (figures 1 and 2).

Bird Slough, which flows around the Campbell property, originates in Clear Lake, 0.6 km (0.4 miles) west of the site. It discharges into The Sny 2.7 km (1.7 miles) east of the site. Historic aerial photographs and topographic maps suggest that Bird Slough has been dredged (USGS 1936, USDA 1936). An unnamed tributary of Bird Slough originates in the northwest corner of the Campbell property and flows east through a wetland along the north edge of the site draining the northwest portion of the Campbell property (figures 1 and 2). In a low area on the western side of the Campbell property, an existing wetland covers approximately 0.5 hectares (1.2 acres) (figure 2). Northeast of the Shepherd site is a borrow pit; water from this pit discharges into Bird Slough through a culvert under the Shepherd access road.

On July 25, 1993, the Sny Levee ruptured 1.3 km (0.8 miles) north of the proposed compensation site. Debris in the utility lines indicates that the depth of flood waters exceeded 5 m (17 ft). Water marks on the Campbell home show that the water was approximately 3 m (10 ft) deep for a significant period.

Ground Water

Throughout the monitoring period, the stage of the Mississippi River has remained at higher elevations than the water levels in the monitoring wells, indicating a hydraulic gradient away from the Mississippi River (figure 7). Data from monitoring wells installed in the lower unit and stage data for the Mississippi River at Hannibal, Missouri (USCOE 1997), show that water-level changes in the monitoring wells generally follow the rise and fall of the Mississippi River stage (figure 7), particularly during spring floods. Both the direction of the hydraulic gradient (away from the river) and the water-level responses in the monitoring wells suggest that water from the Mississippi River discharges to the aquifer underlying the field site (the lower unit of sand).

Water-level elevations in the monitoring wells installed in the lower unit of sand are higher than the elevation of Bird Slough, indicating a hydraulic gradient toward Bird Slough and suggesting that ground water from the lower unit of sand discharges into Bird Slough. Figure 8, a contour map of the water-level elevations on May 24, 1994, shows the local direction of ground-water flow in the lower unit. Figure 9 is a schematic cross section showing that ground water flows from the Mississippi River toward the site, and locally from the field site to Bird Slough.

Figure 8 shows a ground-water mound at monitoring well location 3. Well site 3 is in a topographically high area, where surface water does not pond. Therefore, it is unlikely that the mound is a result of surface-water discharge. Instead, it appears that the ground-water mound is related to discharge from the Mississippi River to the aquifer underlying the site and the land surface topography. The mound is depressed to the south by ground-water discharge to Bird Slough and to the north by lower topography and ground-water discharge to the existing wetland.

Hydrographs of water-level elevations and water-level depth below land surface for individual well locations in Appendix B show (1) the hydrologic relationships between the middle and lower units, and (2) the seasonal variability in water levels. Figure 10, a hydrograph of well locations 2 and 4 and the hydrographs in Appendix B, show that the water-level elevations in the monitoring wells installed in the lower unit, at times, exceeded the boundary between the middle and lower units. This suggests

that the lower unit is partially confined by the middle unit. Figure 10 and the other hydrographs (Appendix B) also show that the differences between the water-level elevations in the monitoring wells installed in the middle and lower units at well locations 2 through 5 are generally very small. This indicates that leakage occurs between the two units and suggests that the middle unit only partially confines the underlying aquifer. At monitoring-well location 2 the water-level elevation in the lower unit has both risen above and dropped below that of the confined unit, suggesting that the vertical hydraulic gradient changes directions.

At all well locations (except well 6 where the middle unit is absent) water levels in wells completed in the lower unit usually dropped below the boundary between the middle and lower units during late summer and early fall. This suggests that conditions change seasonally between confined and unconfined. The duration of confined conditions varies by well location. At monitoring-well locations 2, 3, 4, 5 and 8 the water level in the lower-monitoring wells has remained above or dropped only slightly below the boundary between the upper and middle units. Along the north edge of the site, at well locations 1, 7 and 9, the water levels in wells in the lower unit, except during the spring floods, were nearly always below the boundary between the middle and lower unit. The persistent unconfined conditions at locations 1, 7 and 9, as compared with the rest of the site, are likely due to the higher elevation of the top of the lower unit of sand along the north edge and ground-water discharge from the lower unit into Bird Slough.

Water levels were monitored at Shepherd from May 1994 through March 1997. The water levels in the lower unit, as on the Campbell property, generally fluctuate with changes in the Mississippi River stage (figure 11). The lower unit has generally remained under confined conditions at well locations 10 and 12, and unconfined conditions at well location 11. The water levels in wells 10 and 12 rose to within 30 cm of the land surface during the spring floods of 1995 and 1996. (Appendix B).

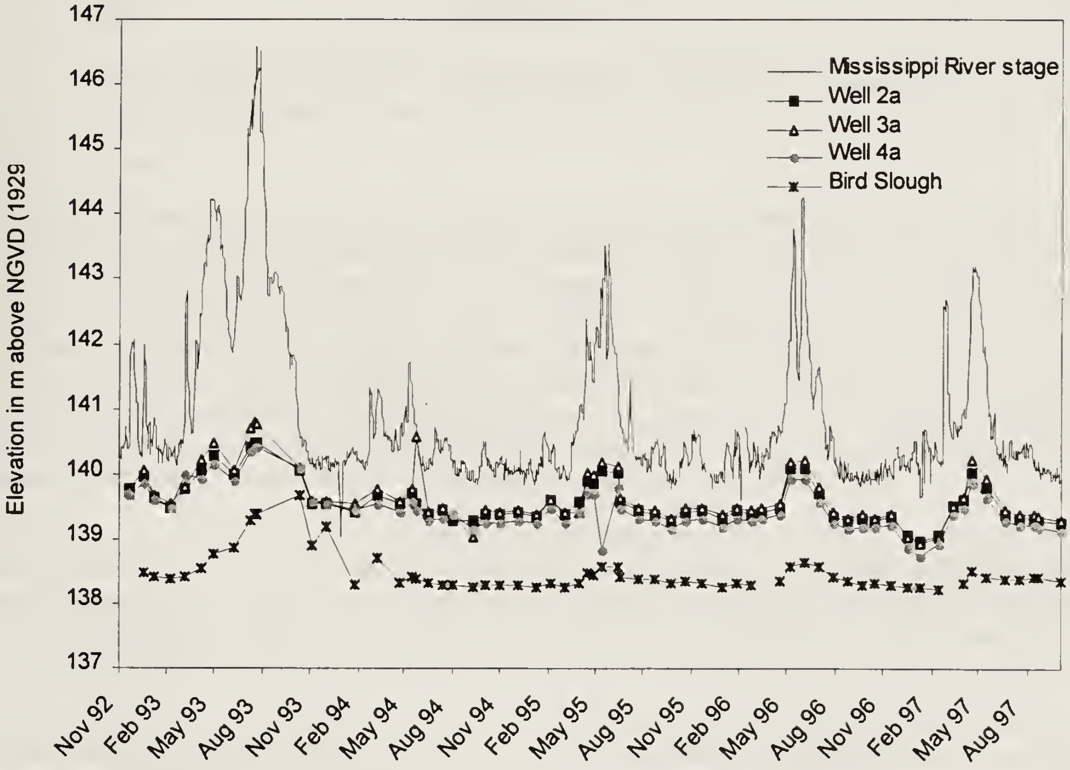


Figure 7 Hydrograph comparing water-level elevations of the Mississippi River, Bird Slough, and monitoring wells installed in the lower unit of sand.

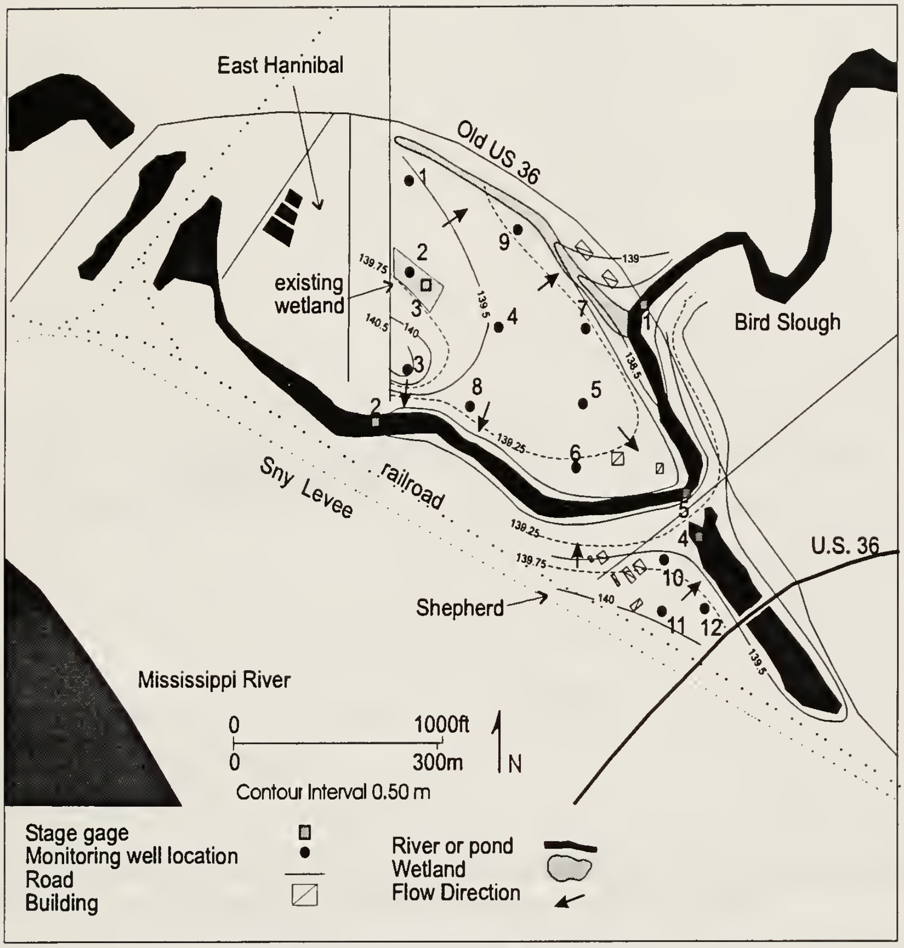


Figure 8 Water-level elevations and ground-water flow directions in the lower unit on May 24, 1994. Elevations are referenced to NGVD, 1929.

Existing Wetland

The existing wetland occurs at this site because (1) it is a basin that collects surface-water runoff and direct precipitation, (2) it is underlain by low-permeability sediments, and (3) the potentiometric surface of the lower unit is close to the land surface during the spring and early summer. Hydrographs for wells 2 and 4 (figure 10), both installed in the existing wetland, show that high ground-water levels support the existing wetland. The water levels in these wells rose to near or above the land surface during the spring and summer of 1993 and in 1995 through 1997, suggesting that ground water was moving upward from the lower unit of sand toward the land surface. Before the levee break, during the flood in July 1993, the water level in well 2a reached the top of the monitoring well and the water depth in the existing wetland exceeded 1 m (3 ft).

During the spring of 1994, which had smaller-magnitude spring floods than the other monitoring years, only several small puddles of surface water (less than 0.05 m or 2 inches deep) occurred in the existing wetland. These puddles were likely the result of precipitation and surface-water inflow, because hydrographs for wells 2 and 4 (figure 10), show that the water levels in the monitoring wells did not rise to land surface during the spring of 1994.

Monitoring wells were not installed in the middle and upper units until May 1994. We are making the assumption that during the springs of 1993 and 1994, the elevation of the potentiometric surface in the lower unit of sand closely matched the water table in the middle and upper units. This assumption

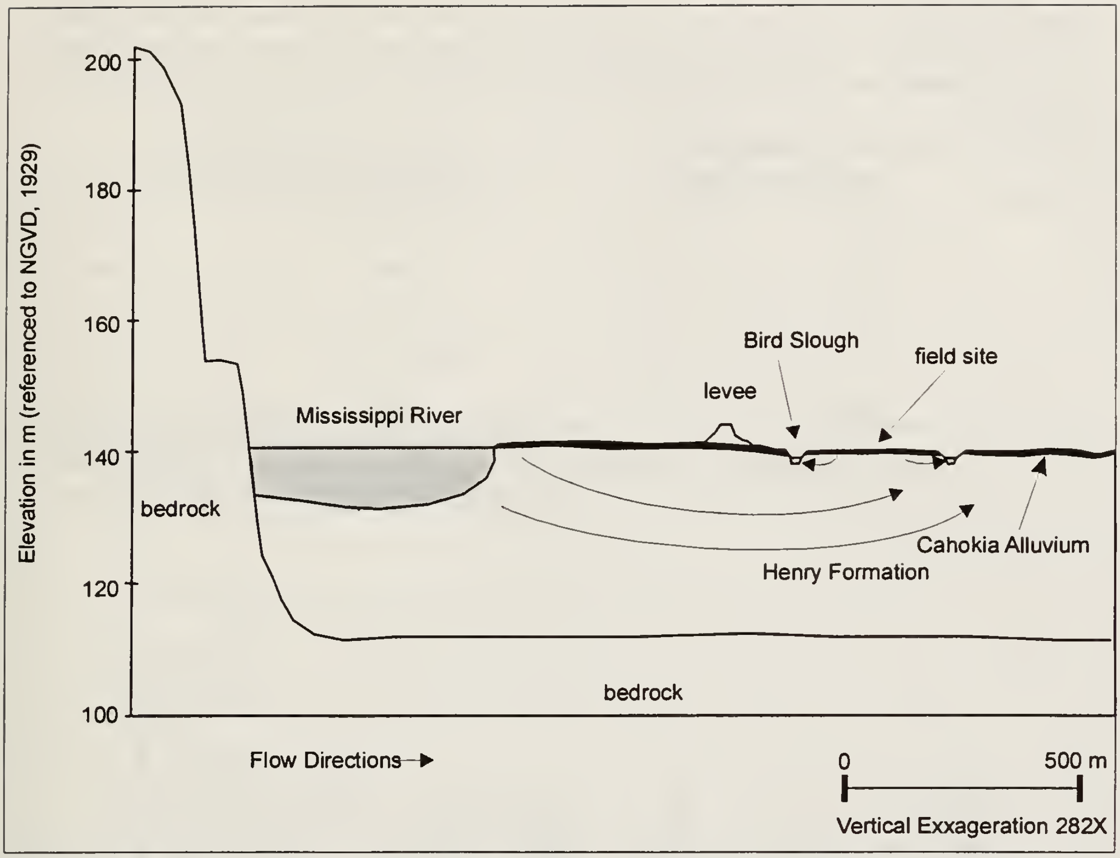


Figure 9 Cross section showing the ground-water-flow relationships existing between the Mississippi River, Bird Slough and the field site. Elevations are referenced to NGVD 1929.

is based on the observations in 1995 through 1997 that the elevation differences between the water table in the middle and upper units and the potentiometric surface in the lower unit were generally small.

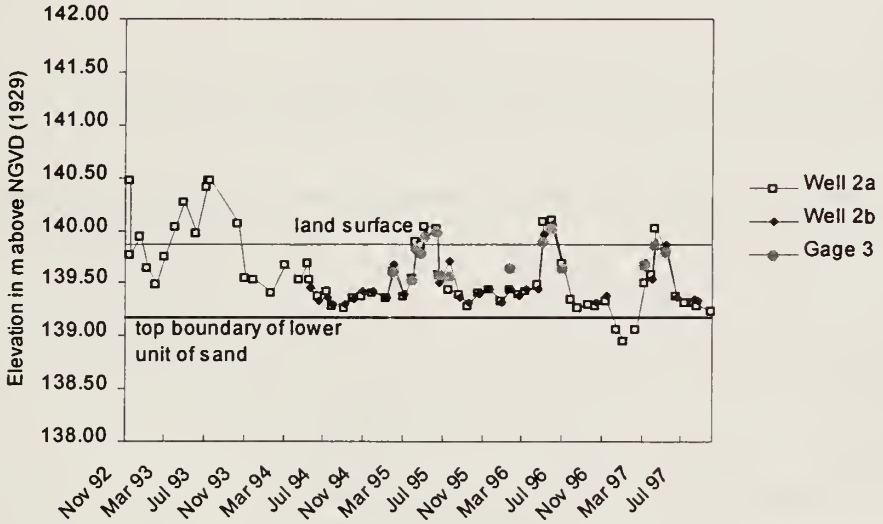
Climate, River Stage and Wetland Hydrology

An area meets the wetland hydrology requirement for a jurisdictional wetland if saturation occurs within 0.3 m of the land surface for more than 12.5 percent of the growing season (U.S. Army Corps of Engineers 1987). The growing season in Pike County, defined as the time between the median last occurrence of -2°C temperatures in the spring and the median first occurrence -2°C temperatures in the fall, runs for 205 days from April 6 through October 27 (USDA 1997). In Pike County 12.5 percent of the growing season is 26 days. Table 1 shows the monitoring well locations that met the wetland hydrology requirement during the monitoring period.

Table 1 Monitoring well locations that met the wetland hydrology requirement of water levels within 30 cm of the land surface for more than 26 days during the growing season, and precipitation as percent of normal (1961-1990) for March through May (from MCC for Hannibal, Missouri).

Year	Monitoring well locations that met the wetland hydrology requirement	Precipitation as percent of normal for March through May
1993 [1]	2, 3, 4, 5, 6, 7, 8 [2]	87
1994	none	97
1995	2, 4, 7, 8, 9, 12	141
1996	2, 4, 7, 8, 9, 12	103
1997 [3]	2,4	90

[1] Monitoring wells 9 through 12 not yet installed.
[2] During March through May wells 2, 4, 7, and 8 met the wetland hydrology requirement
[3] Monitoring wells 10 through 12 were not read.



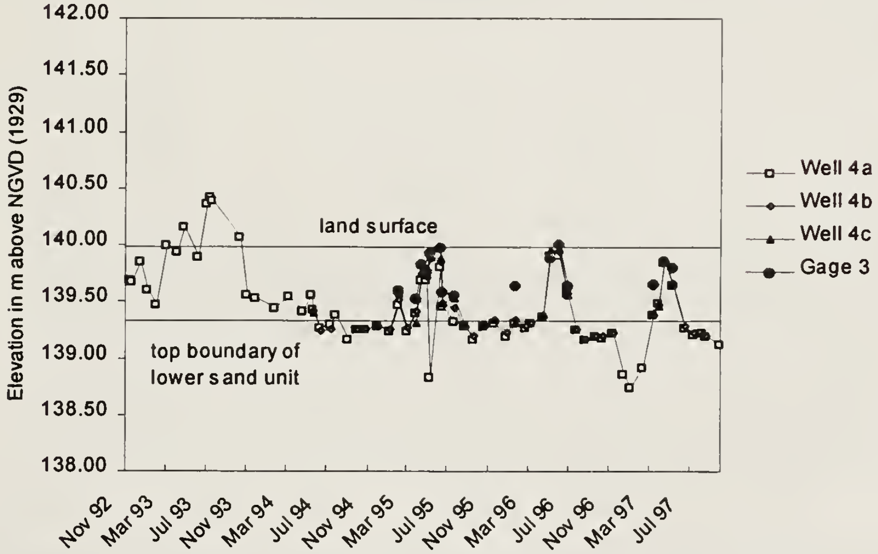


Figure 10 Water-level elevations at well locations 2 and 4, and at gage 3 in the existing wetland.

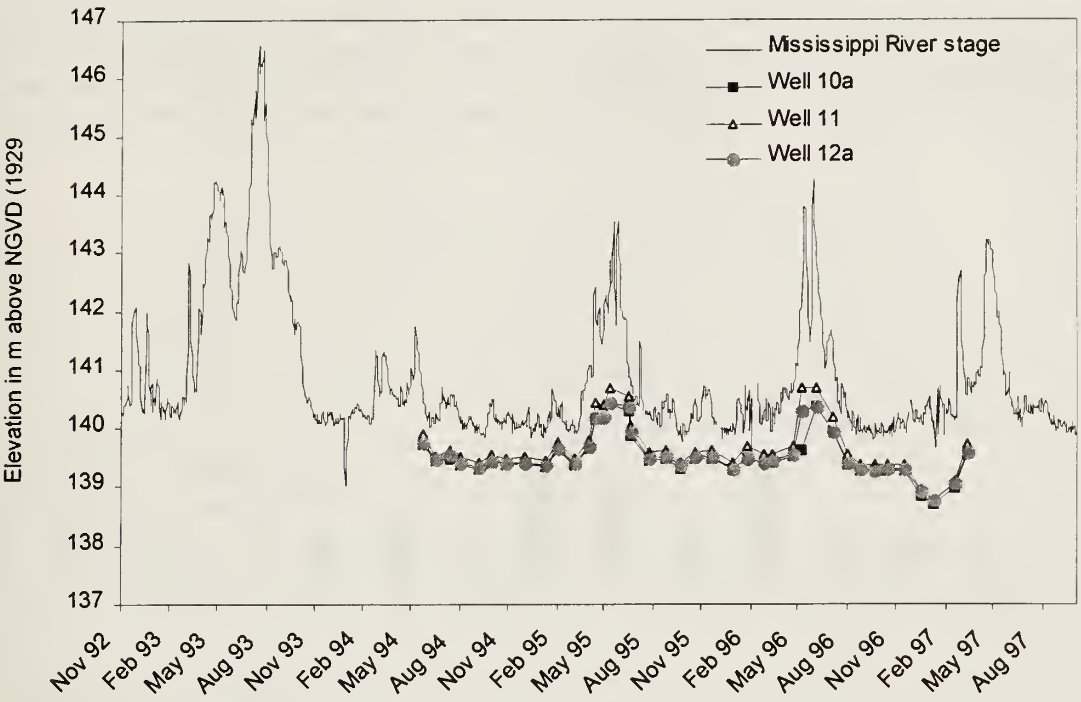


Figure 11 Hydrograph comparing water levels at the Shepherd site to the Stage of the Mississippi River.

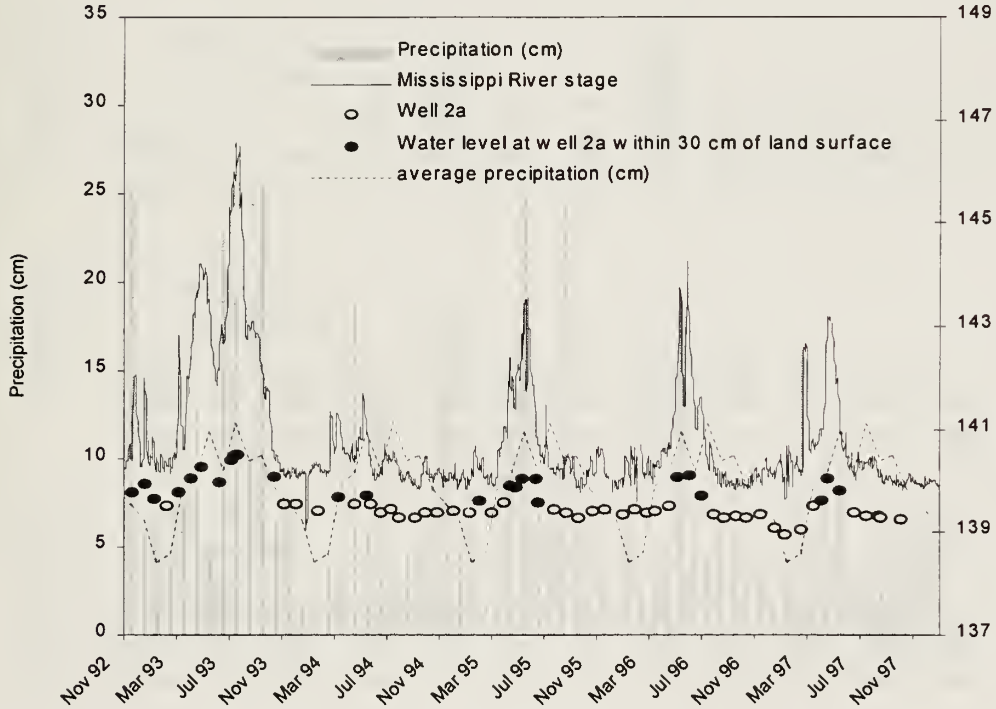


Figure 12 Mississippi River stage compared the water-level elevation in well 2, and monthly and average precipitation. The darkened circles indicate that the water level in well 2a was within 30 cm of the land surface.

Water-level fluctuations in the monitoring wells are a function of both local rainfall and river stage. The highest water levels in the monitoring wells occurred in the spring when precipitation and or river stage were high (figure 12). Figure 13 shows monthly precipitation during the monitoring period. Exceedence curves of river-stage elevations at Hannibal (figure 14) show the percentage of days during the year that the daily river stage exceeded a given elevation. The graph shows that 1993 had

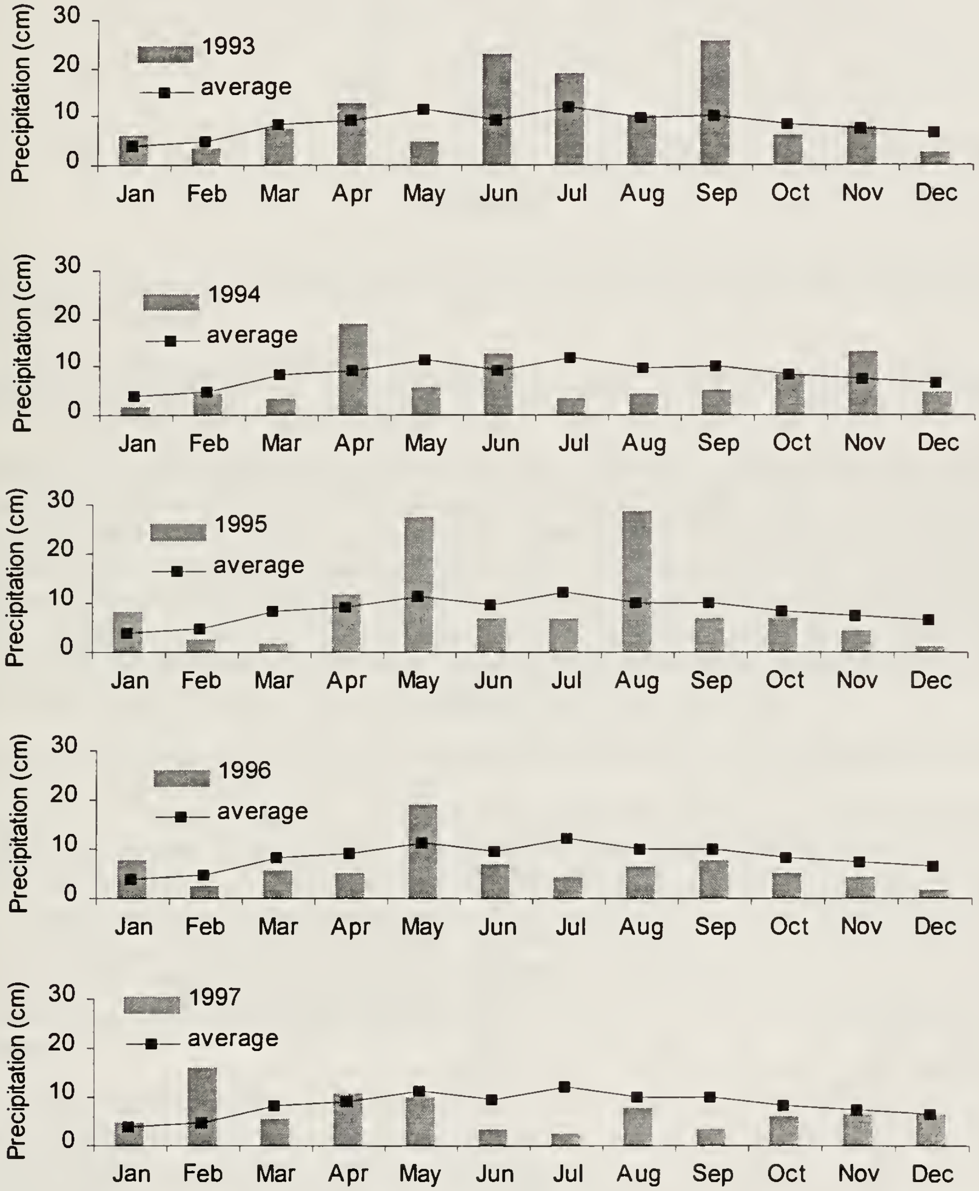


Figure 13 Monthly precipitation at Hannibal, Missouri compared to the 30-year average (Midwestern Climate Center 1997).

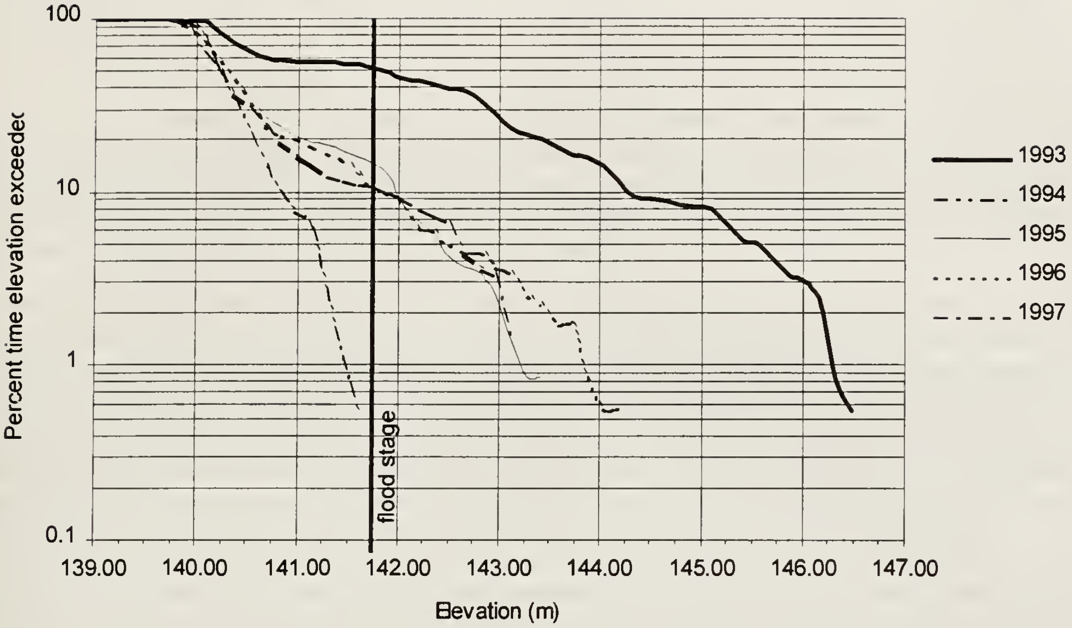


Figure 14 An exceedance curve showing the percentage in days that the stage of the Mississippi River exceeded various elevations.

high stages for the longest period, 1994 had the lowest stages, 1995 and 1997 were similar, and that 1996 had slightly higher stages than 1995 and 1997.

A comparison of river stage, local precipitation and water levels in monitoring wells shows that river stage and precipitation both influence water levels in monitoring wells. Figure 14 shows that 1993 had prolonged high river stages. Although rainfall during March through May of 1993 was 87% of normal, four of eight monitoring well sites met the wetland hydrology requirement during May through June (table 1). In contrast precipitation was 97% of normal during March through May of 1994, but in 1994 none of the monitoring wells locations met the wetland hydrology requirement. Figure 14 shows that 1994 had the lowest river stages. This suggests that the higher water levels that occurred during the spring of 1993 were due to river stage and not to local rain fall.

In contrast, a comparison of 1995 and 1997 shows the influence of local precipitation. More well locations met the wetland hydrology requirement in 1995 than in 1997. Precipitation for March through May was 141% of normal in 1995 and in 90% of normal in 1997. Figure 14 shows that the height and duration of river stage for the two years were very similar. This suggests that the higher water levels in 1995 were due to higher local precipitation.

Table 2 Monthly frequency of the occurrence of the annual maximum stage during 1960 through 1997 on the Mississippi River at Hannibal, Missouri.

	Percent Time
January	0
February	3
March	8
April	43
May	16
June	11
July	13
August	0
September	0
October	3
November	3
December	0

Table 2 shows that during 70% of the time, the annual maximum stage occurred during April through June, the first three months of the growing season. This suggests that during most years the maximum flood will occur during the growing season. The annual

maximum stages in 1994, 1995 and 1996 occurred in May, and the annual maximum stage in 1997 occurred in April.

WETLAND DESIGN

Construction of the wetland was completed in July 1997. The wetland was created by excavating a shallow ground-water-fed basin. The excavation depth lowered the existing land surface to an elevation of 139.75 m (458.50 ft). This elevation is roughly equivalent to the land-surface elevation of the existing wetland, which ranges from 139.43 to 139.89 m (457.45 to 458.96 ft). Berms with 2:1 slopes were constructed around the perimeter of the wetland.

The ISGS evaluated the wetland design in November 1994, based on 1994 water levels, to predict whether it would achieve wetland hydrology. The proposed IDOT wetland boundary was readjusted (1) to avoid excavating in areas where excavation would thin the sediments overlying the lower unit to less than 0.25 m (0.82 ft), (2) to avoid excavating in areas with little likelihood of supporting wetland hydrology (based on water levels in the lower unit from the spring of 1994), and (3) to use topographically high areas as the wetland perimeter instead of constructing berms. The boundary was adjusted by drafting water-level contour maps for the lower unit and comparing them with other maps (topographic, isopach and top of sand elevation) by overlaying them on a light table.

The middle and upper units were left in place because their removal would likely alter the site hydrology. The minimum thickness of the combined middle and upper units in the existing wetland is about 0.25 m (0.82 ft). This suggests that a wetland can exist if a combined thickness of at least 0.25 m (0.82 ft) is maintained for the middle and upper units. Maps of the elevation of the top of the sand unit and the combined thickness of the middle and upper units (figures 4 and 5) allowed for the

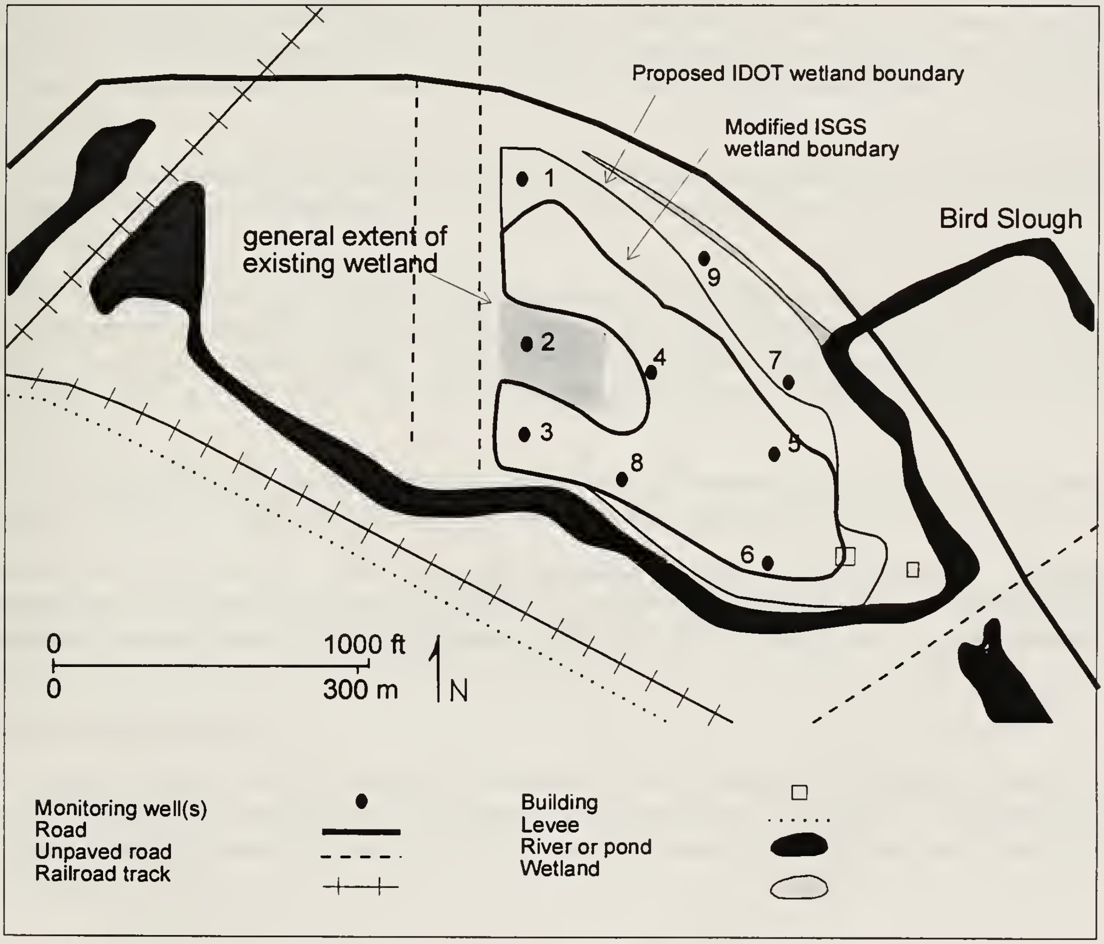


Figure 15 Map of the wetland design showing ISGS suggested modifications.

adjustment of the wetland boundary to exclude areas where excavation would thin the sediments overlying the top of the lower sand to less than 0.25 m (0.82 ft). Excavation to an elevation of 139.75 m (458.50 ft) within the ISGS-suggested boundary (figure 15) would leave more than 0.5 m (1.6 ft) of sediment covering the lower unit of sand over all of the wetland, except along the north edge.

The maps of water-level elevations in the lower unit and hydrographs of water-level depth below land surface allowed for the elimination of areas where water levels were too low to support a wetland. Figure 15 shows the proposed IDOT wetland boundary and the modified boundary proposed by the ISGS. The area, within the ISGS-modified boundary, covers approximately 4.94 hectares (12.2 acres).

The hydrology of the constructed wetland is uncertain because (1) excavation may change the permeability of the middle and upper units due to compaction and unloading, (2) evapotranspiration rates may change, because current equilibrium conditions will be changed, and (3) water levels may change as the system adjusts to the new conditions.

SUMMARY

1.The site geology consists of a 0.10- to 1.77-m- (0.33- to 5.81-ft-) thick upper layer of sand that partially covers the site, a 0.18- to 1.68-m- (0.33- to 5.81-ft-) thick middle unit of clayey silt, and a lower unit of sand. The entire thickness of the lower sand was not penetrated during drilling, but according to well-log records and geologic maps it underlies much of the flood plain and extends down to bedrock at a depth of 30 m (98 ft) below land surface.

2. The site is underlain by a large, confined/unconfined aquifer composed of sand and gravel (the lower unit of sand) that is hydrologically connected to the Mississippi River. Ground water flows from the Mississippi River toward the site. Water levels in the monitoring wells responded to stage changes in the Mississippi River. Locally, ground water discharges from the lower unit of sand into Bird Slough.

3. The existing wetland is maintained, in part, by high ground-water levels in the underlying aquifer. During periods when the Mississippi River is high, ground water discharges to land surface in the existing wetland.

4. IDOT has expanded the existing wetland through excavation to an elevation of 139.75 m (458.50 ft), the approximate elevation of the existing wetland. The ISGS suggested that wetland creation be limited to areas (1) where excavation would not thin the sediments overlying the lower unit of sand more than 0.25 m (0.82 ft) and (2) where hydrologic conditions are likely to support wetland hydrology.

5. The hydrology of the constructed wetland will vary yearly, depending on the stage and duration of spring flooding on the Mississippi River, and the amount of direct precipitation.

6. Predictions of post-construction hydrology are limited because (1) excavation may change the permeability of the middle and upper units due to compaction and unloading, (2) evapotranspiration rates may change, because current equilibrium conditions will be changed, and (3) water levels may change as the system adjusts to the new conditions.

ACKNOWLEDGMENTS

Tim Young, Christine Fucciolo, and Mark Hart assisted with well installation. Mark Hart, Brett Denny, and Michael Phillips helped survey the locations and elevations of the wells. Jim Geiger, and Christine Fucciolo assisted in mapping the surficial sediments. Michael Miller and Dave Larson reviewed the report.

REFERENCES

Berg, R.C., and J.P. Kempton, 1988, Stack-unit Mapping of Geologic Materials in Illinois to a Depth of 15 meters, Illinois State Geological Survey, Circular 542, Champaign, IL, 23 P.

*Compton, R.R., 1962, Manual of Field Geology, John Wiley and Sons, New York, 378 p.

*Krumbein, W.C., and L.L. Sloss, 1963, Stratigraphy and Sedimentation, Second Edition, W. H. Freeman Company, San Francisco 600 p.

Larkin, R.G., and J.M. Sharp, 1992, On the relationship between river-basin geomorphology, aquifer hydraulics, and ground-water flow directions in alluvial aquifers, Geological Society of America Bulletin, v. 104, p. 1608-1620.

Lineback, J.A., 1979, Quaternary Deposits of Illinois, Illinois State Geological Survey, Champaign, map scale 1:500,000.

Meyer, R.R., and A.N. Turcan, 1955, Geology and ground-water resources of the Baton Rouge area Louisiana, US Geological Survey Water-Supply Paper 1296, United States Government Printing Office, Washington, 138 p.

Midwest Climate Center, 1997, Illinois State Water Survey, available online: Midwest Climate Information Systems [http://mcc.sws.uiuc.edu/].

Piskin, K., and R.E. Bergstrom, 1975, Glacial drift in Illinois: thickness and character, Illinois State Geological Survey, Circular 490, Champaign, 35 p.

U.S. Army Corps of Engineers, 1987, Corps of Engineers Wetlands Delineations Manual, Department of the Army, Vicksburg, Mississippi, 100 p.

U.S. Army Corps of Engineers, April 1997, Rock Island District, Water Control Center, Gage Information, available online at: http://soulchaser.ncr.usace.army.mil/.

U.S. Department of Agriculture, Soil Conservation Service, 1991, Hydric soils of Illinois (rev. January 31, 1992), in Hydric Soils of the United States, Miscellaneous Publication 1491, Washington, D.C.

U.S. Department of Agriculture, Soil Conservation Service, 1992, Hydric Soils of Pike County (issued November 9, 1992), Pittsfield, Illinois, 4 p.

U.S. Department of Agriculture, Soil Conservation Service (unpublished) Soil Survey Maps of Pike County, Illinois, Pittsfield, Illinois.

U.S. Department of Agriculture, 1936, Aerial photograph number AR-1-06.

U.S. Geological Survey, 1936, Hannibal, Missouri-Illinois, 15-Minute Series, (Topographic): U.S. Department of the Interior, Geological Survey, Reston, Virginia, map scale 1:62,500.

U.S. Geological Survey, 1971, Hannibal East Quadrangle, Missouri-Illinois, 7.5-Minute Series (Topographic): U.S. Department of the Interior, Geological Survey, Reston, Virginia, map scale 1:24,000.

Willman, H.B., J.C. Frye, J.A. Simon, K.E. Cleg, C. Collinson, J.A. Lineback, and T.C. Buschbach,, 1967, Geologic Map of Illinois, Illinois State Geological Survey, Champaign, map scale 1:500,000.

Willman, H.B., E. Atherton, T.C. Buschbach, C. Collinson, J.C. Frye, M.E. Mopkins, J.A. Lineback, and J.A. Simon, 1975, Handbook of Illinois Stratigraphy, Illinois State Geological Survey, Bulletin 95, Champaign, 261 p.

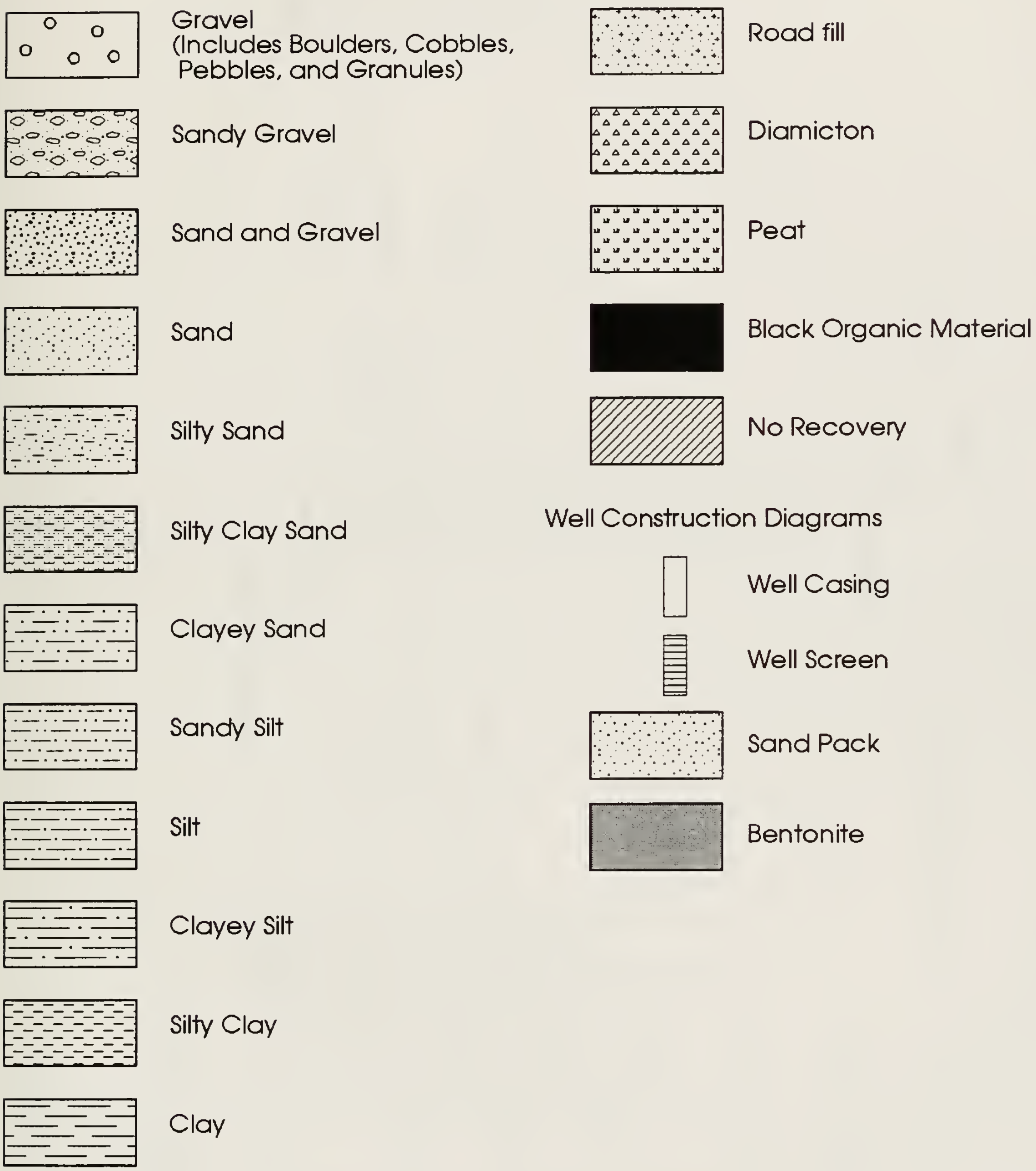
Willman, H.B., and Frye, J.C., 1970, Pleistocene Stratigraphy of Illinois, Illinois State Geological Survey, Bulletin 94, Champaign, 204 p.

---

*Used in Appendix A, Part 1.

APPENDIX A Geologic Logs of Borings and Geologic Cross Sections at East Hannibal

Part 1 Index of Geologic Symbols[1]



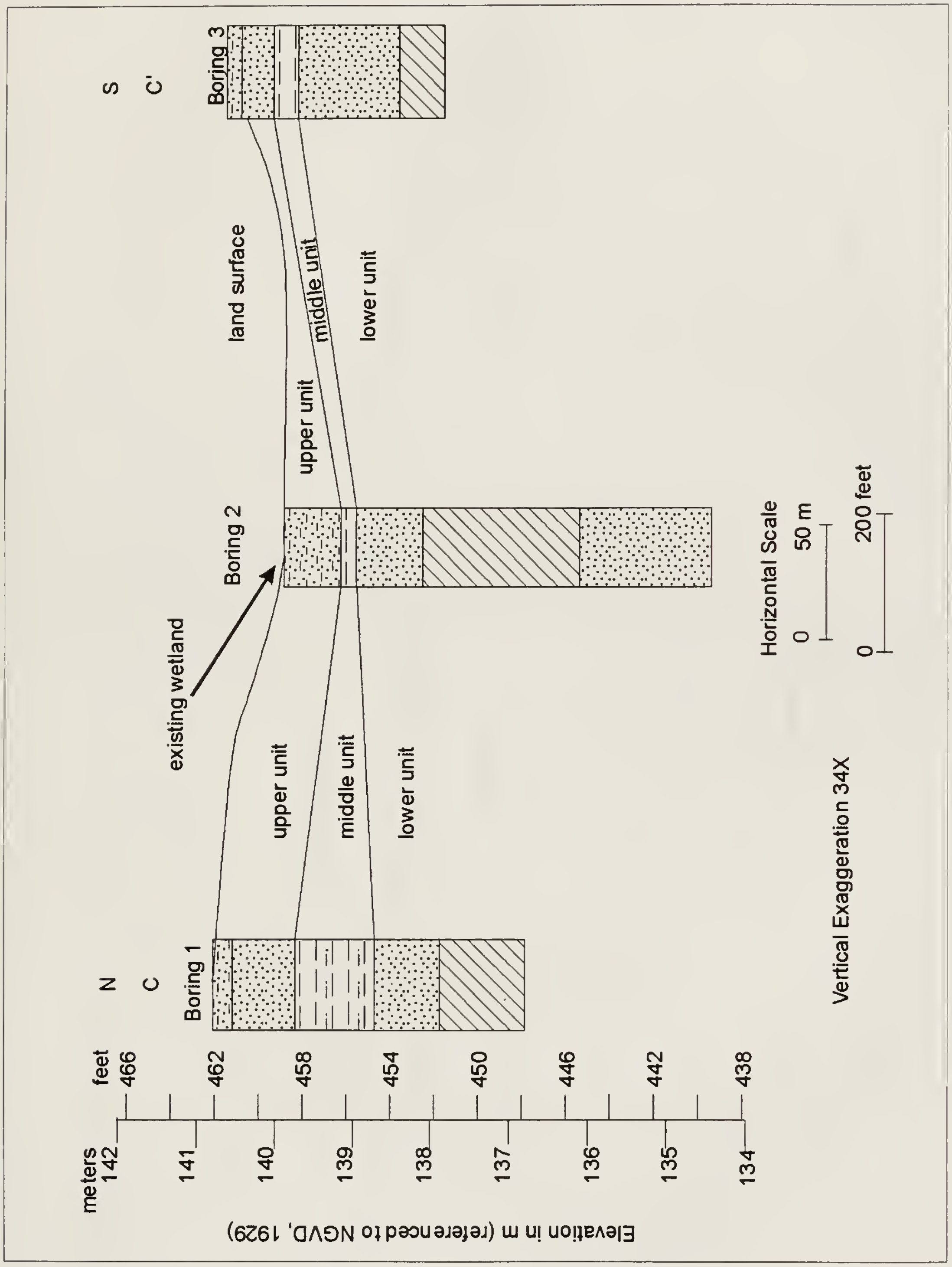
---

[1]Sediment textural classification modified from Krumbein and Sloss (1963) and Compton (1962).

APPENDIX A *continued*

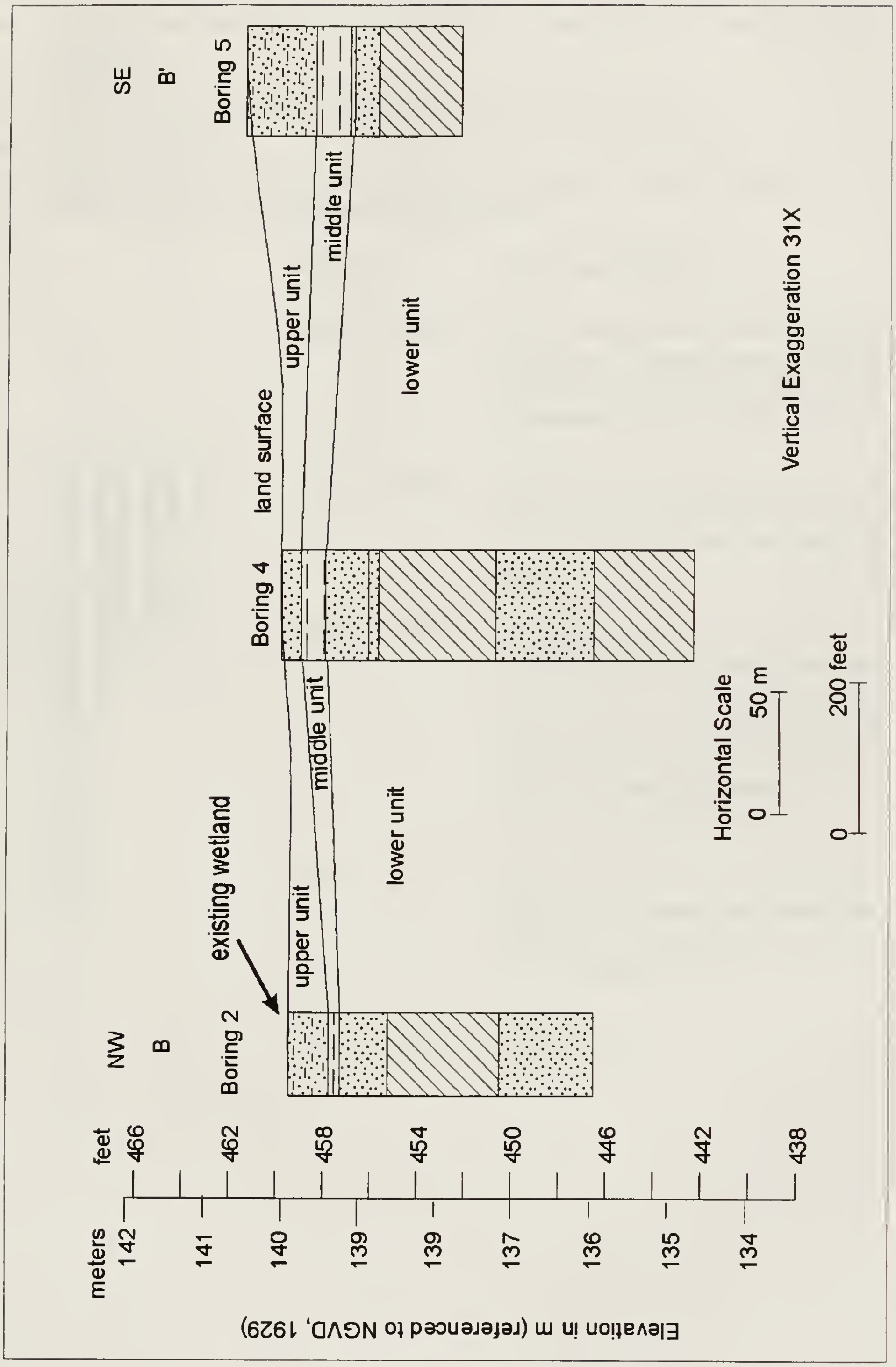
Part 2 Geologic Cross Sections (lines of cross section in figure 2)

CROSS SECTION C-C'



APPENDIX A *continued*

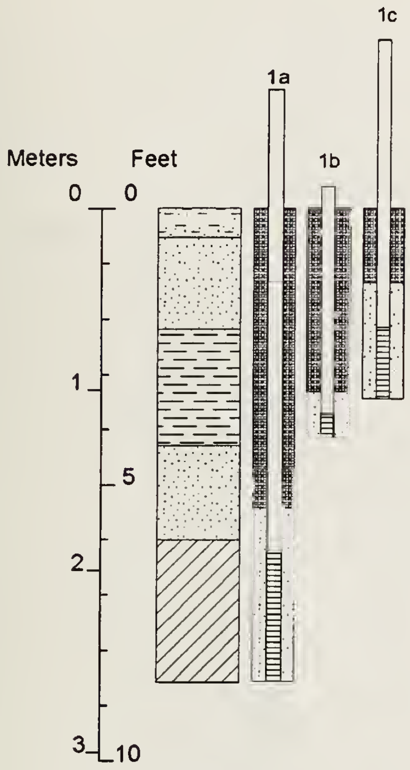
Part 2 Geologic Cross Sections (lines of cross section in figure 2)



APPENDIX A *continued*
Part 3 **Geologic Logs of Borings**

EAST HANNIBAL #1

Location SW NW NW NE, T4S, R8W, Sec. 17, Hannibal East, MO.-ILL. 7.5' Quadrangle
Date 10/26/92
Field Crew Nancy Rorick, Jim Miner, Christine Fucciolo, and Tim Young
Weather Conditions Cool and sunny
Comments Mobile drill rig, 15-cm diameter hollow stem auger, continuous sampler.
Well Information Installed 3 wells, well information in Appendix D.

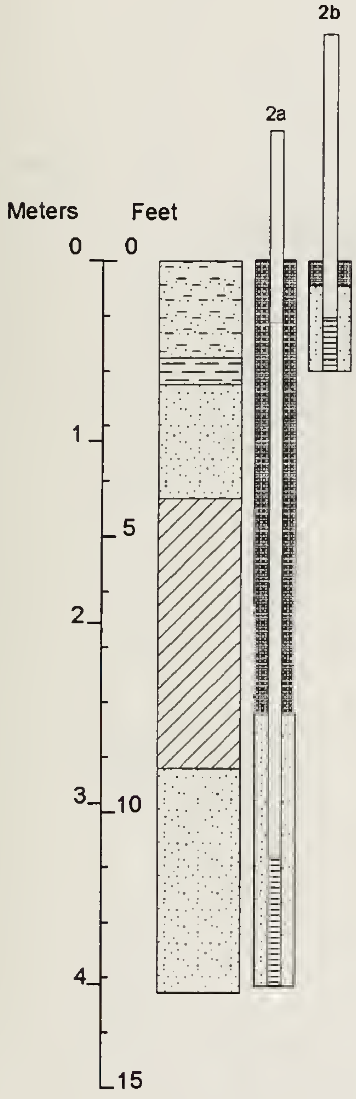


Depth	Unit Descriptions
0.00 - 0.15 m	**Silty sand**; light brownish gray (10YR 6/2); slightly silty, coarse, well-sorted, quartz sand with some potassium feldspars.
0.15 - 0.66 m	**Sand**; dark grayish brown (10YR 4/2) to light brown; coarse to medium, rounded, well-sorted sand.
0.66 - 1.30 m	**Laminated silty clay**; dark gray (2.5YR 4/0) with brown mottles (7.5YR 5/2); laminations are 0.5 cm (0.2 in.) thick and consist of coarse, sorted, rounded dark gray (2.5Y 4/1) sand; contains roots, twigs, and cattail fragments.
1.30 - 1.73 m	**Sand**; very coarse, well rounded, sorted sand; sand laminated by grain size; some laminae contain very fine pebble gravel.
1.73 - 2.64 m	**No recovery.**

APPENDIX A *continued*
Part 3 Geologic Logs of Borings

EAST HANNIBAL #2

Location NE SW NW NE, T4S, R8W, Sec. 17, Hannibal East, MO.-ILL. 7.5' Quadrangle
Date 10/28/92
Field Crew Nancy Rorick, Jim Miner, Christine Fucciolo, and Tim Young
Weather Conditions Cool and sunny
Comments Mobile drill rig, 15-cm diameter hollow stem auger, continuous sampler.
Well Information Installed 2 wells, well information in Appendix D.

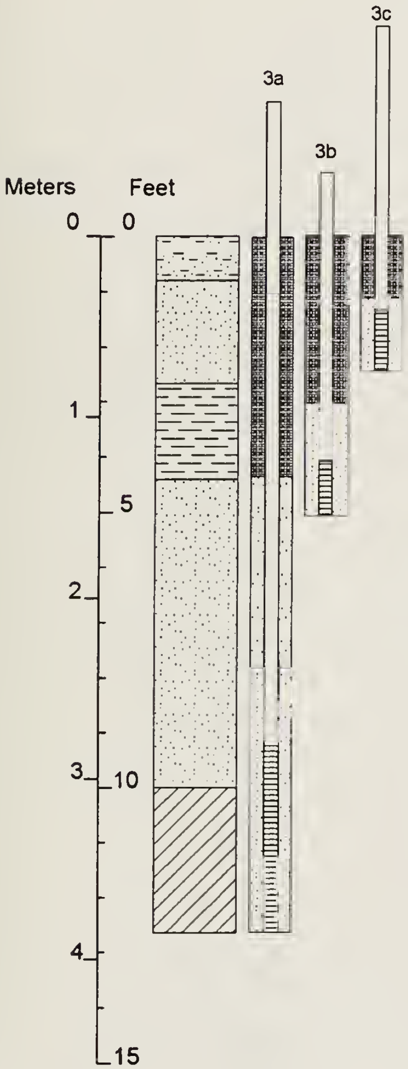


Depth	Unit Descriptions
0.00-0.53 m	**Silty sand**; dark gray (5YR 4/1) changing to reddish brown (5YR 5/3) near roots; becomes richer in silt and clay; laminated at 0.25-0.53 m (0.83-1.75 ft); distinct lower boundary.
0.53 - 0.69 m	**Laminated silty clay**; gray (2.5YR 5/1); contains organic material; strong odor of hydrogen sulfide; gradual lower boundary.
0.69 - 1.30 m	**Sand**; gray (2.5YR 6/1) from 0.69-0.76 m (2.25-2.50 ft) and from 0.76-1.30 m (2.50-4.27 m) light gray (10YR 7/2); laminated but laminations are not distinct; some roots preserved; medium, quartz sand containing some magnetite, potassium feldspars, and rock fragments.
1.30 - 2.80 m	**No recovery.**
2.80 - 4.01 m	**Sand**; recovered 0.69 m (2.25 ft); from 2.80-2.75 m (9.17-9.67 ft) brown, medium, well-sorted, rounded, non-calcareous, laminated, quartz sand containing potassium feldspars, magnetite, and rock fragments; from 2.95-3.49 m (9.67-11.42 ft) the sand has the same texture and mineralogy as above, but is gray and has 1.0-cm (0.4-in.) thick laminae.

APPENDIX A *continued*
Part 3 Geologic Logs of Borings

EAST HANNIBAL #3

Location SW SW NW NE, Sec. 17, T4S, R8W, Hannibal East, MO.-ILL. 7.5' Quadrangle
Date 10/27/92
Field Crew Nancy Rorick, Jim Miner, Christine Fucciolo, and Tim Young
Weather Conditions Cool and sunny
Comments Mobile drill rig, 15-cm diameter hollow stem auger, continuous sampler.
Well Information Installed 3 wells, well construction information in Appendix D.

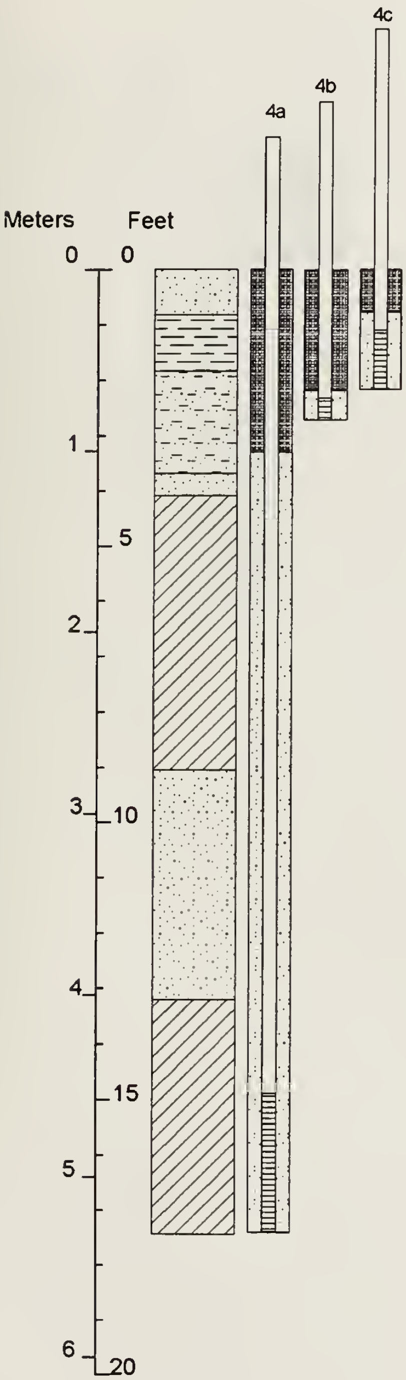


Depth	Unit Descriptions
0.00 - 0.25 m	**Silty sand**; dark brown (7.5YR 4/2) with dark brown mottles (7.5YR 4/4); slightly rounded, sorted, friable, and non-calcareous sand; very little soil development; distinct and convoluted lower boundary.
0.25 - 0.81 m	**Sand;** pinkish white (7.5YR 8/2); clean, well-sorted, medium, friable, non-calcareous sand; slightly laminated by color; lower 5 cm (2 in.) is strongly laminated by color with a gradual increase of fines in darker layers; gradual lower boundary.
0.81 - 1.35 m	**Laminated silty clay;** dark gray (5YR 4/1); contains some friable, fine sand in reddish brown (5YR 5/3) laminae; non-calcareous; contains some organic material.
1.35 - 3.05 m	**Sand;** brown; well rounded, sorted, and laminated sand; medium laminae are 0.5 cm (0.2 in.) thick and are distinguished by a change in potassium feldspars and magnetite grains.
3.05 - 3.85 m	**No recovery.**

APPENDIX A *continued*
Part 3 Geologic Logs of Borings

EAST HANNIBAL #4

Location NE SE NW NE, T4S, R8W, Sec. 17, Hannibal East, MO.-ILL. 7.5' Quadrangle
Date 10/27/92
Field Crew Nancy Rorick, Jim Miner, Christine Fucciolo, and Tim Young
Weather Conditions Cool and sunny
Comments Mobile drill rig, 15-cm diameter hollow stem auger, continuous sampler.
Well Information Installed three wells, well construction information in Appendix D.

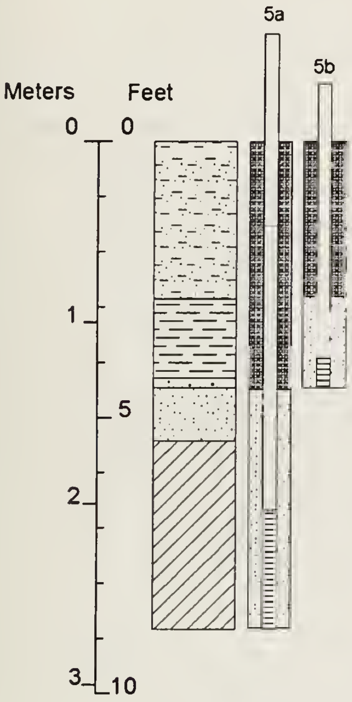


Depth	Unit Descriptions
0.00 - 0.23 m	**Sand**; dark gray (2.5Y 4/1); contains some silt; non-calcareous.
0.23 - 0.66 m	**Silty clay**; dark gray (5YR 4/1) with dark reddish gray (5YR 4/2) mottles; granular structure; non-calcareous; contains a clay enriched zone.
0.66 - 1.12 m	**Silty sand**; blocky structure; laminated with 5-mm (0.1-in.) thick laminae distinguished by color; moisture content is high but not saturated; faint red (2.5YR 4/2) and dark grey (2.5YR 4.0) mottles.
1.12 - 1.24 m	**Sand**; brown; medium to coarse, well-sorted, rounded, non-calcareous quartz sand with some magnetite and potassium feldspar; massive structure.
1.24 - 2.77 m	**No recovery.**
2.77 - 4.14 m	**Sand;** brown; medium to coarse, well-sorted, rounded, non-calcareous quartz sand with some magnetite and potassium feldspar; massive structure.
4.14 - 5.31 m	**No recovery.**

APPENDIX A *continued*
Part 3 **Geologic Logs of Borings**

EAST HANNIBAL #5

Location NE SE NW NE, T4S, R8W, Sec. 17, Hannibal East, MO.-ILL. 7.5' Quadrangle
Date 10/27/92
Field Crew Nancy Rorick, Jim Miner, Christine Fucciolo, and Tim Young
Weather Conditions Cool and sunny
Comments Mobile drill rig, 15-cm diameter hollow stem auger, continuous sampler.
Well Information Two wells installed, well installation information in Appendix D.

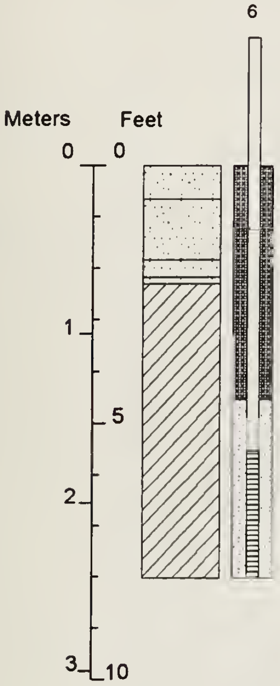


Depth	Unit Descriptions
0.00 - 0.86 m	**Silty sand**; pinkish gray (7.5YR 6/2); fine, rounded non-calcareous sand; slightly mottled; laminated in lower 25 cm (10 in.).
0.86 - 1.30 m	**Silty clay**; grey (5YR 5/1); laminated; few mottles; high organic content; non-calcareous.
1.30 - 1.35 m	**Sand**; light brownish gray (10YR 6/2); fine, well-sorted, and laminated sand.
1.35 - 1.65 m	**Sand;** brown; coarse, well rounded, well-sorted sand; slightly laminated by color; non-calcareous.
1.65 - 2.79 m	**No recovery**.

APPENDIX A *continued*
Part 3 **Geologic Logs of Borings**

EAST HANNIBAL #6

Location NW NE SW NE, T4S, R8W, Sec. 17, Hannibal East, MO.-ILL. 7.5' Quadrangle
Date 10/29/92
Field Crew Nancy Rorick, Jim Miner, Christine Fucciolo, and Tim Young
Weather Conditions Cool and sunny
Comments Mobile drill rig, 15-cm diameter hollow stem auger, continuous sampler.
Well Information One well installed. Well construction information in Appendix D.

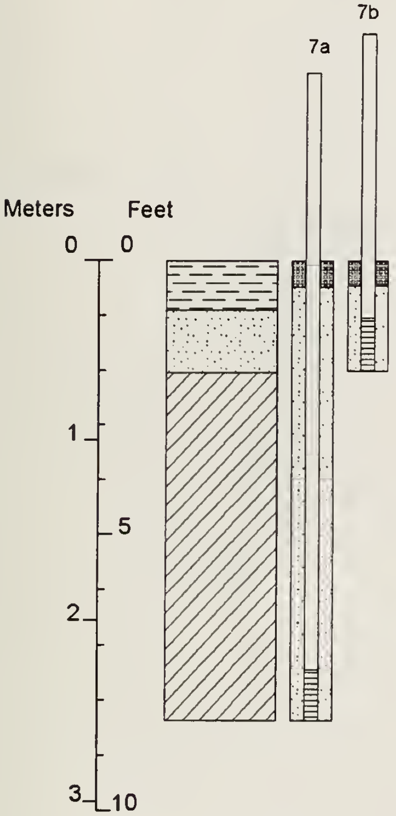


Depth	Unit Descriptions
0.00 - 0.20 m	**Sand;** brown (7.5YR 5/2); sorted, silty, fine sand; high organic content; non-calcareous; massive.
0.20 - 0.56 m	**Sand;** yellow (10YR 7/6); medium, well-sorted, and rounded sand; 5-mm (0.1-in.) thick laminae distinguished by organics and magnetite; contains quartz, potassium feldspars, magnetite, and rock fragments; coarsens with depth; gradual lower boundary.
0.56 - 0.66 m	**Sand;** gray (10YR 6/1); coarse, well-sorted, and laminated sand; high organic content; odor of hydrogen sulfide; abrupt lower boundary.
0.66 - 0.69 m	**Sand;** brownish yellow (10YR 6/6); medium to coarse, well rounded, well sorted sand.
0.69 - 2.44 m	**No recovery.**

APPENDIX A *continued*
Part 3 **Geologic Logs of Borings**

EAST HANNIBAL #7

Location SW SE NW NE, T4S, R8W, Sec. 17, Hannibal East, MO.-ILL. 7.5' Quadrangle
Date 2/5/93
Field Crew Jim Miner and Mark Hart
Weather Conditions Cool and sunny
Comments Hand augered borehole with a 5-cm (2-in.) diameter bucket auger. Core collected by driving a metal pipe into the ground.
Well Information One well installed. Well construction information in Appendix D.

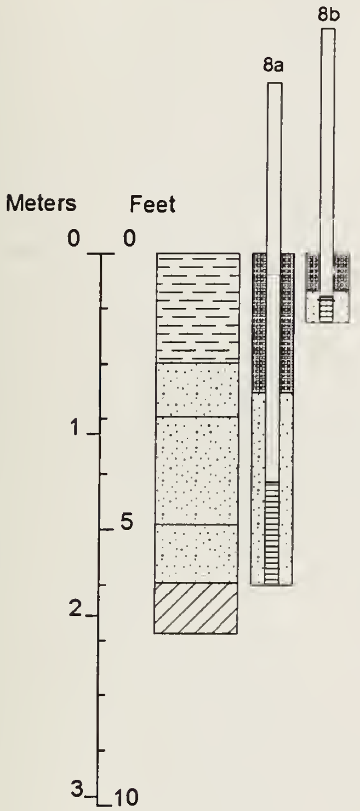


Depth	Unit Descriptions
0.00 - 0.27 m	**Silty clay;** very dark gray (5YR 3/1) with very dark gray mottles (10YR 3/1) along root zones; roots present; abrupt and angular lower boundary.
0.27 - 0.61 m	**Sand;** grayish brown (10YR 5/2) from 0.27 to 0.37 m (0.9 to 1.2 ft), below 0.37 m (1.2 ft) color is brownish yellow (10YR 6/6); laminated, medium, subrounded, poorly sorted sand; 3-cm (0.1-ft) thick laminae.
0.61 - 2.53 m	**No recovery.**

APPENDIX A *continued*
Part 3 Geologic Logs of Borings

EAST HANNIBAL #8

Location	SE SW NW NE, T4S, R8W, Sec. 17, Hannibal East, MO.-ILL. 7.5' Quadrangle
Date	2/5/93
Field Crew	Jim Miner and Mark Hart
Weather Conditions	70's and sunny
Comments	Hand augered borehole with a 5-cm (2-in.) diameter hand auger.
Well Information	Two wells installed. Well construction information in Appendix D.

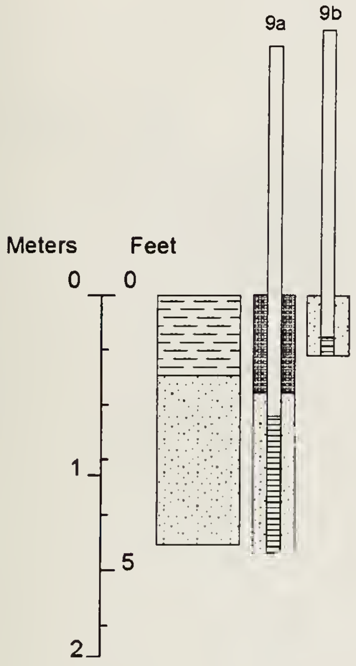


Depth	Unit Descriptions
0.00 - 0.60 m	**Clay;** black; sandy and silty; high organic content; sulfur like odor.
0.60 - 0.90 m	**Sand;** black color; silty; high clay content; high organic content.
0.90 - 1.50 m	**Sand;** gray; slightly silty, coarse, rounded, sorted sand.
1.50 - 1.83 m	**Sand;** gray-green; coarse.
1.83 - 2.07 m	**No recovery.**

APPENDIX A *continued*
Part 3 **Geologic Logs of Borings**

EAST HANNIBAL #9

Location NW SE NW NE, T4S, R8W, Sec. 17,
Date 5/18/94
Field Crew Nancy Rorick and Jim Miner
Weather Conditions Warm and sunny
Comments Hand augered borehole with 5-cm (2-in.) diameter bucket auger.
Well Information Well point was driven past the bottom of the borehole. Two wells installed. Well construction information in Appendix D.

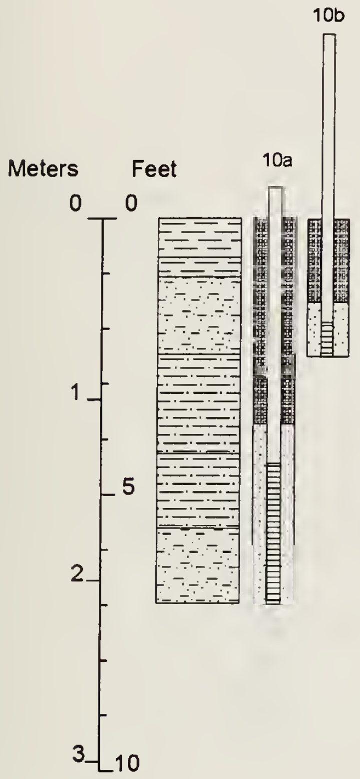


Depth	Unit Descriptions
0.00 - 0.39 m	**Silty clay;** very dark grayish brown (10YR 3/2); many, faint, fine, dark yellowish brown (10YR 4/4) mottles; massive structure; 5% organics consisting of roots, grass and twigs; gradual lower boundary.
0.39 - 0.45 m	**Silty clay;** very dark gray (10YR 3/1); common, fine, distinct dark yellowish brown (10YR 4/4) mottles; 5-10% organic fragments; 1-mm thick sand laminae composed of fine, well-sorted, rounded sand.
0.45 - 1.43 m	**Sand;** brown (10YR 5/3); medium, rounded, well-sorted quartz sand containing 5% rock fragments.

Part 3 Geologic Logs of Borings

EAST HANNIBAL #10

Location NW SW SE NE, T4S, R8W, Sec. 17,
Date 5/18/94
Field Crew Nancy Rorick and Jim Miner
Weather Conditions Warm and sunny
Comments Hand augered borehole with 5-cm (2-in.) diameter bucket auger.
Well Information Two wells installed. Well construction information in Appendix D.



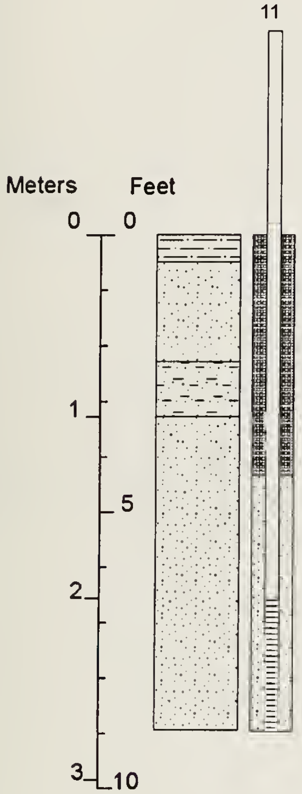
Depth	Unit Descriptions
0.00 - 0.22 m	**Silty clay;** very dark gray (10YR 3/1); fine, common, prominent, strong brown (7.5YR 4/6) mottles occurring as rhizospheres; thin sand laminae (less than 1 mm thick) separated by 4-5 mm-thick layers of silty clay; fine, well-sorted, quartz sand.
0.22 - 0.34 m	**Silty clay;** very dark grayish brown (10YR 3/2); fine, common, prominent, strong brown mottles; thin sand laminae (less than 1-mm thick) separated by 4-5 mm layers of silty clay; fine, well-sorted, quartz sand.
0.34 - 0.76 m	**Silty sand;** brown (10YR 4/3); fine, well-sorted, rounded sand.
0.76 - 1.30 m	**Clayey silt**; dark yellowish brown (10YR 4/6); common, fine and distinct mottles occurring as rhizospheres. Sand grains visible with hand lens are fine, well-sorted and rounded quartz.
1.30 - 1.70 m	**Clayey silt;** very dark grayish brown (10YR 3/2); common, fine, distinct, dark yellowish brown (10YR 3/6) mottles; massive structure; sand visible with hand lens is fine, rounded quartz.
1.70 - 2.12 m	**Silty sand;** brown (10YR 4/3); well-sorted, fine and rounded sand containing less than 1% MnO_2 nodules and less than 1% chert grains.

APPENDIX A *continued*

Part 3 **Geologic Logs of Borings**

EAST HANNIBAL #11

Location NW SW SE NE, T4S, R8W, Sec. 17,
Date 5/18/94
Field Crew Nancy Rorick and Jim Miner
Weather Conditions Warm and sunny
Comments Hand augered borehole with 5-cm (2-in.) diameter bucket auger.
Well Information One well installed. Well construction information in Appendix D.

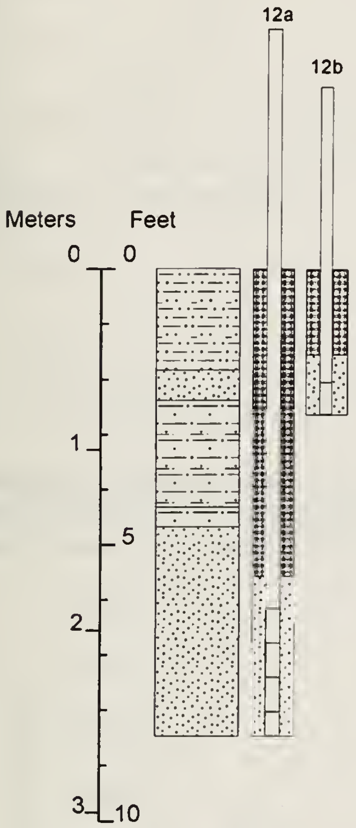


Depth	Unit Descriptions
0.00 - 0.16 m	**Clayey silt;** very dark gray (10YR 3/1); few, fine, prominent strong brown (7.5YR 4/6) mottles.
0.16 - 0.70 m	**Sand;** brown (10YR 4/3); fine, well-sorted, rounded sand.
0.70 - 1.00 m	**Silty sand;** brown (10YR 4/3); fine, rounded, well-sorted, slightly cohesive sand.
1.00 - 2.72 m	**Sand;** brown (10YR 4/3); fine, rounded, well-sorted quartz sand with 2-3% rock fragments including muscovite and MnO_2 nodules.

APPENDIX A *continued*
Part 3 **Geologic Logs of Borings**

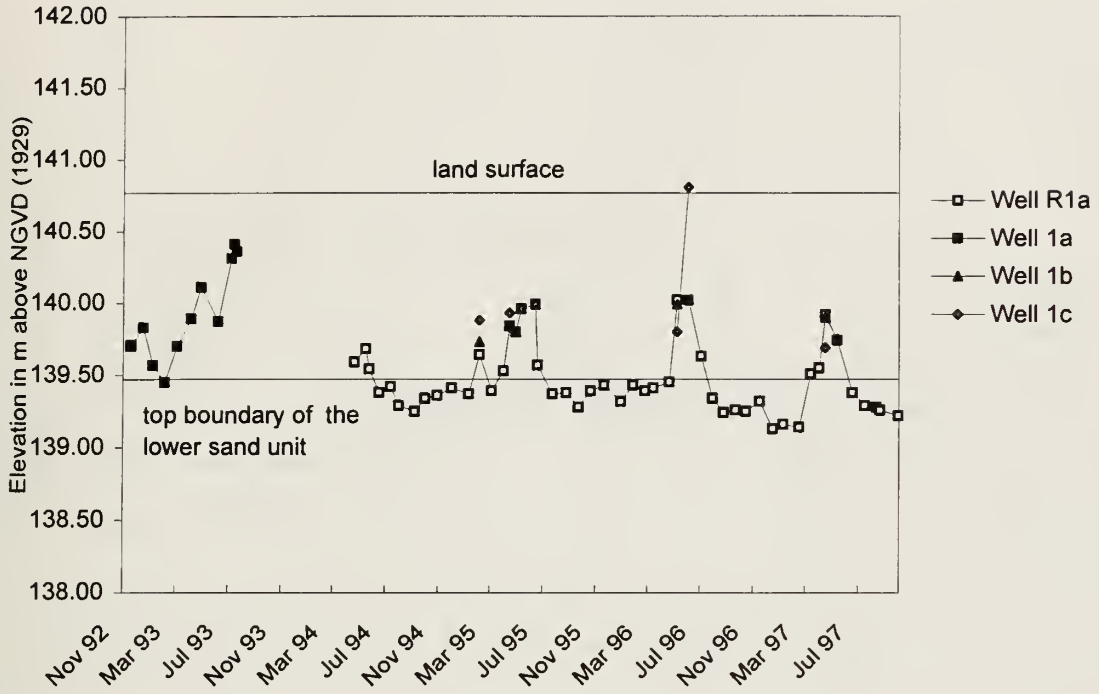
EAST HANNIBAL #12

Location NW SW SE NE, T4S, R8W, Sec. 17,
Date 5/18/94
Field Crew Nancy Rorick and Jim Miner
Weather Conditions Warm and sunny
Comments Hand augered borehole with 5-cm (2-in.) diameter bucket auger.
Well Information Two wells installed. Well construction information in Appendix D.

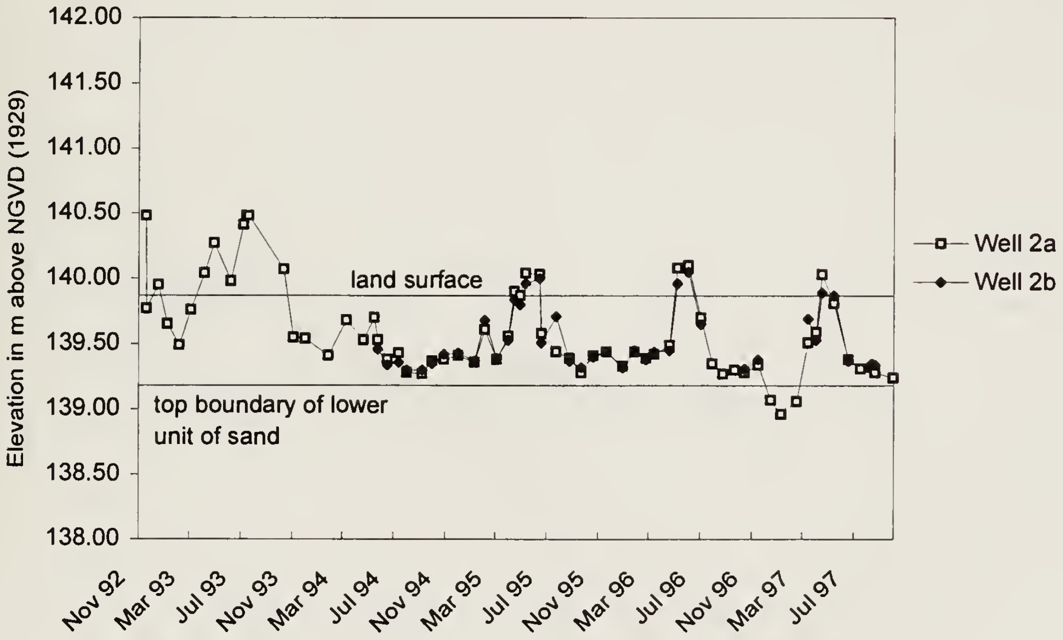


Depth	Unit Descriptions
0.00 - 0.55 m	**Sandy silt;** very dark grayish brown (10YR 3/2); common, medium, faint, dark yellowish brown (10YR 3/4) mottles.
0.55 - 0.73 m	**Silty sand;** gray (5Y 5/1); few, fine, distinct, black (10YR 2/1) mottles; strong odor (may be a septic field).
0.73 - 1.31 m	**Clayey silt;** black (N 2.5/).
1.31 - 1.42 m	**Clayey silt;** very dark gray (10YR 3/1); common, fine, distinct dark yellowish brown (10YR 4/4) mottles.
1.42 - 2.58 m	**Sand**; yellowish brown (10YR 5/4); fine, well-sorted, rounded, quartz sand with 1-2% lithic fragments (dark mineral magnetite or MnO_2).

APPENDIX B Monitoring-well hydrographs

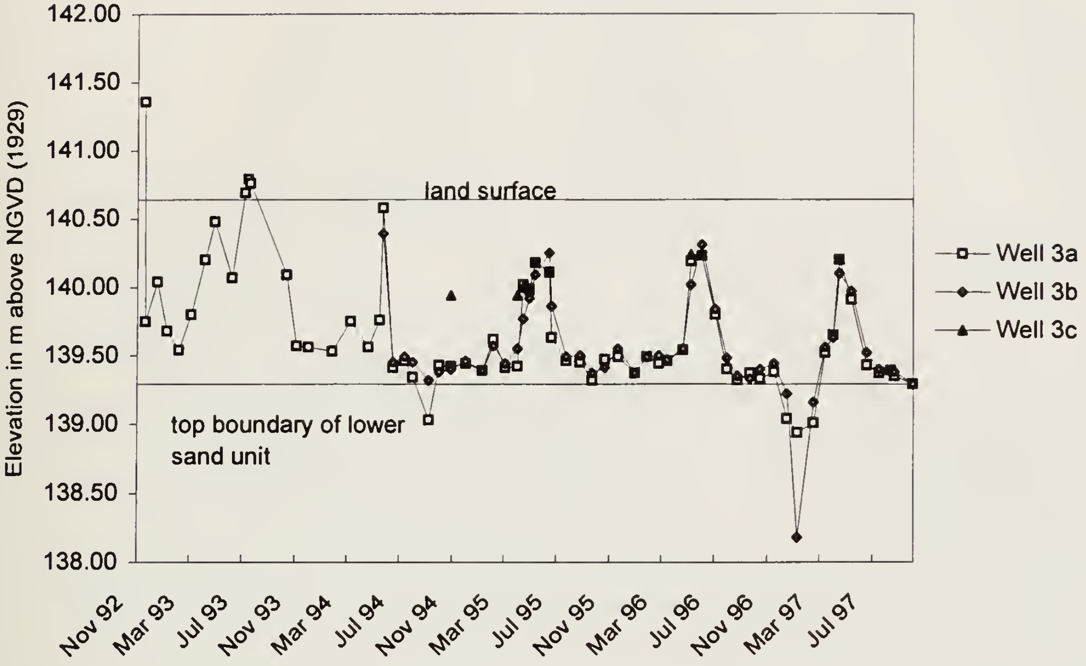


Hydrograph 1 Water levels at well location 1. Monitoring well 1L was destroyed during the 1993 flood. Monitoring well R1L was installed on April 20, 1994. Monitoring wells 1M and 1U were installed on May 18, 1994. Otherwise, an absence of data indicates that the monitoring wells were dry.

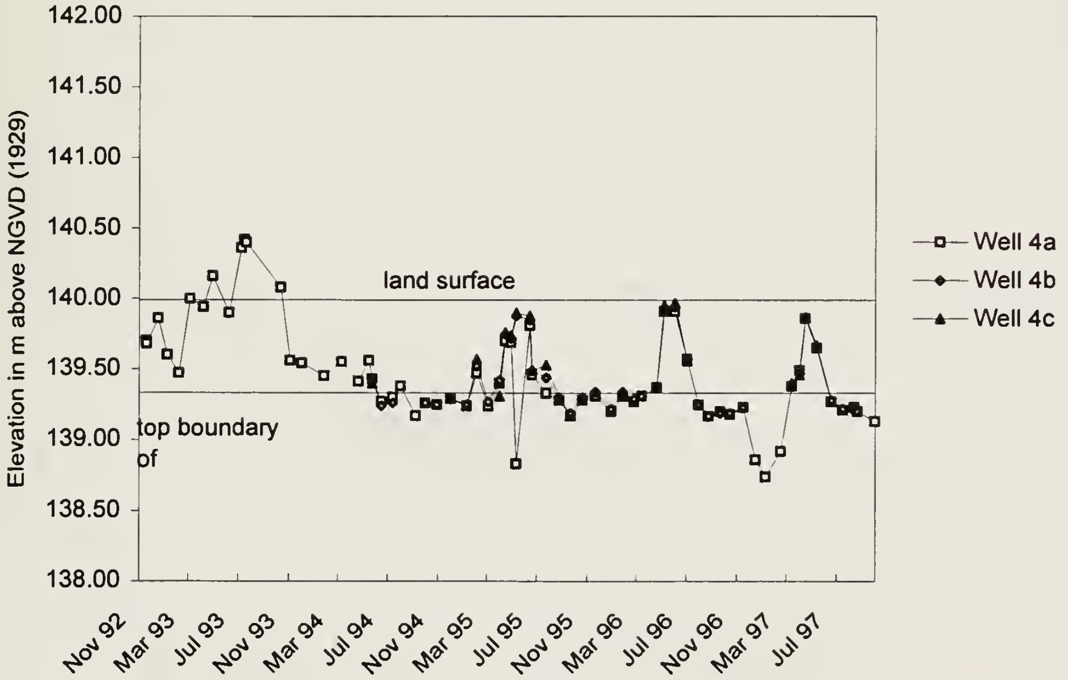


Hydrograph 2 Water levels at well location 2. Monitoring well 2U was installed on May 18, 1994. Monitoring well 2U was damaged by fire in April 1996. Otherwise, an absence of data indicates that the monitoring wells were dry.

APPENDIX B Monitoring-well hydrographs

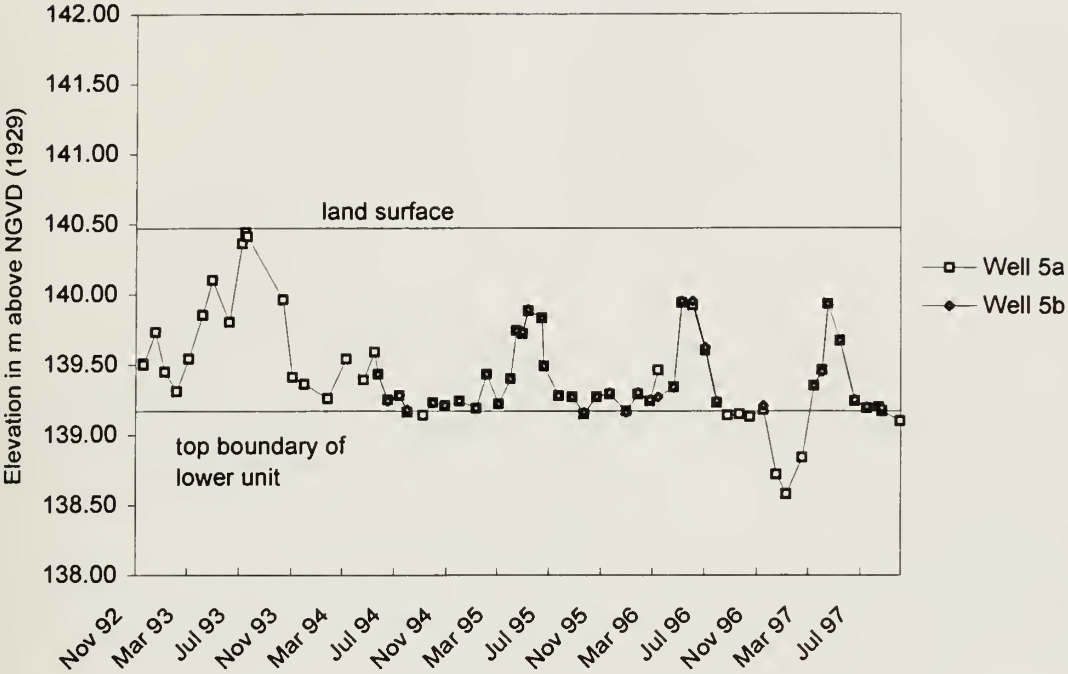


Hydrograph 3 Water levels at well location 3. Monitoring wells 3M and 3U were installed on May 18, 1994. Otherwise, an absence of data indicates that the monitoring wells were dry.

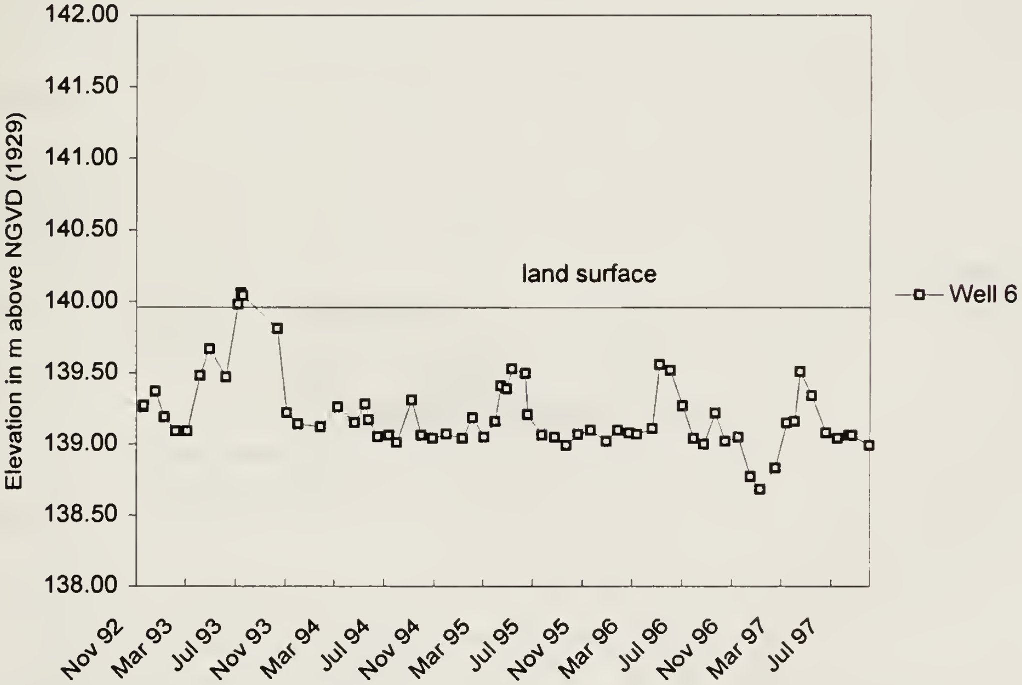


Hydrograph 4 Water levels at well location 4. Monitoring wells 4M and 4U were installed on May 18, 1994. Otherwise, an absence of data indicates that the monitoring wells were dry.

APPENDIX B Monitoring-well hydrographs

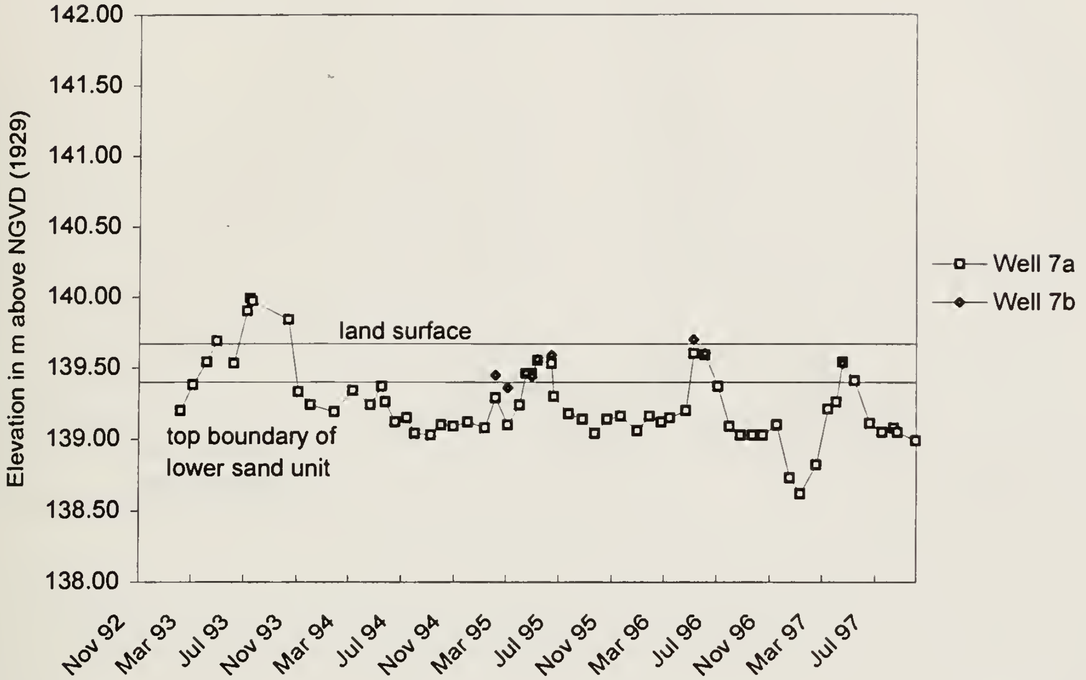


Hydrograph 5 Water levels at well location 5. Monitoring wells 5M and 5U were installed on May 18, 1994. Otherwise, an absence of data indicates that the monitoring wells were dry.

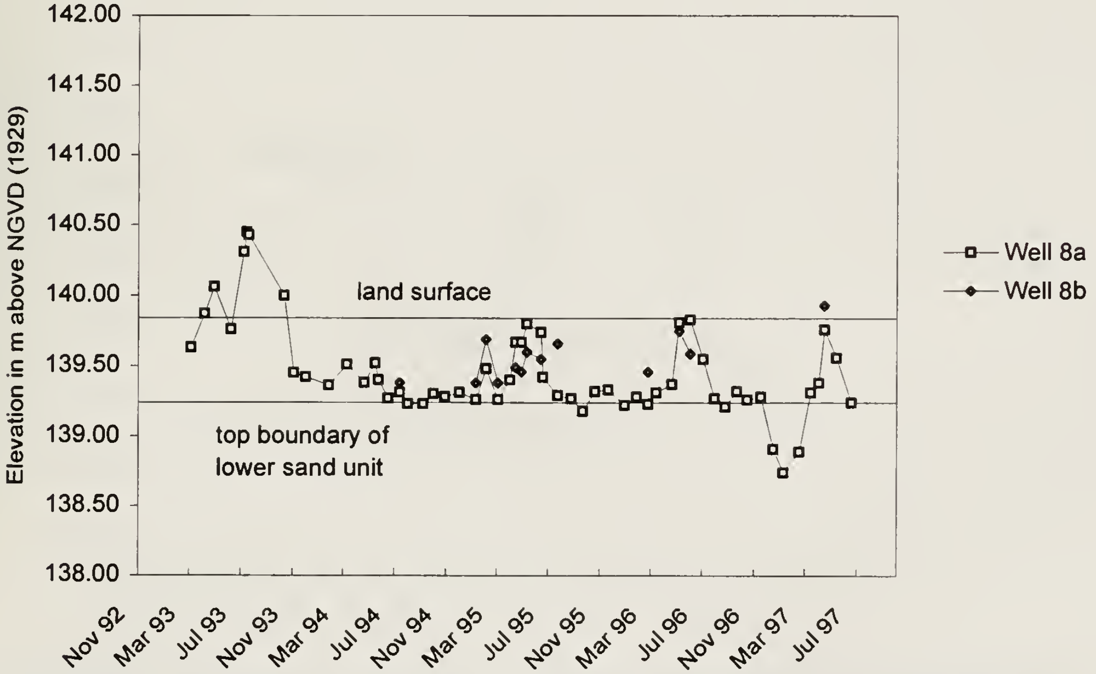


Hydrograph 6 Water levels at well location 6.

APPENDIX B Monitoring-well hydrographs

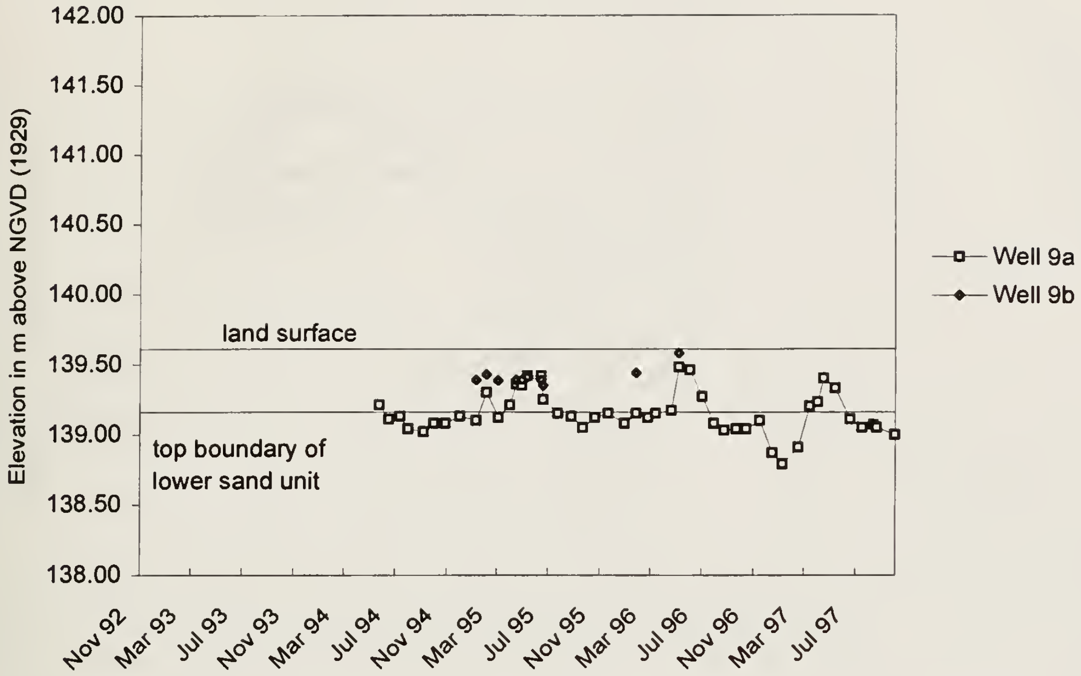


Hydrograph 7 Water levels at well location 7. Monitoring wells 7M and 7U were installed on May 18, 1994. The water in monitoring well 7U was frozen on January 27, 1996. Otherwise, an absence of data indicates that the monitoring wells were dry.

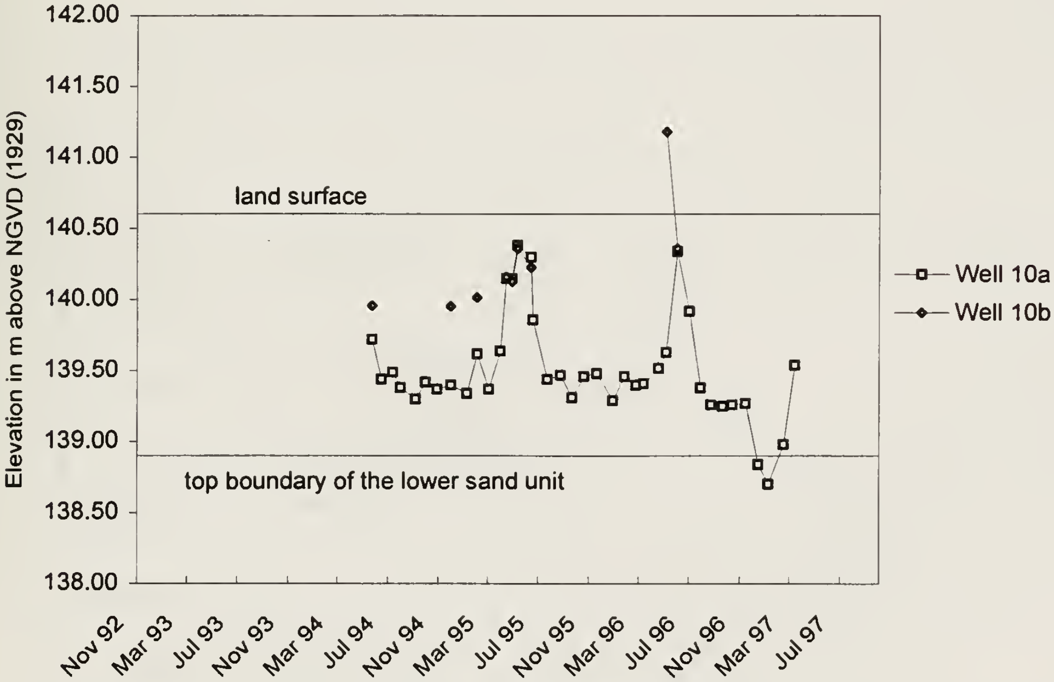


Hydrograph 8 Water levels at well location 8. Monitoring wells 8M and 8U were installed on May 18, 1994. Otherwise, an absence of data indicates that the monitoring wells were dry.

APPENDIX B Monitoring-well hydrographs

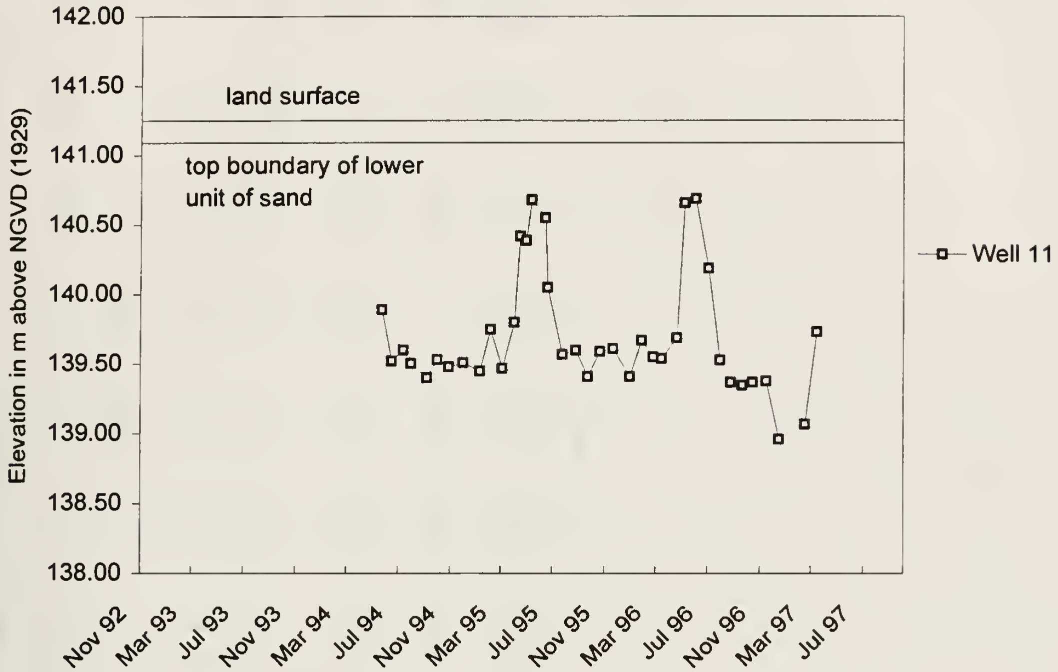


Hydrograph 9 Water levels at well location 9. Monitoring wells 9M and 9U were installed on May 18, 1994. Otherwise, an absence of data indicates that the monitoring wells were dry.

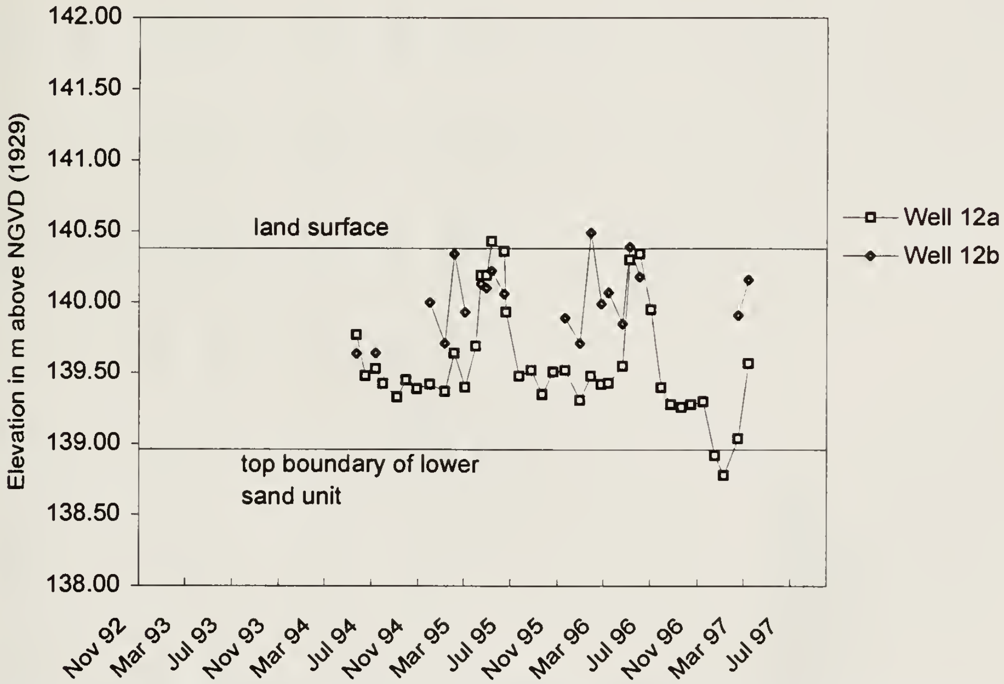


Hydrograph 10 Water levels at well location 10. Monitoring wells 10M and 10U were installed on May 18, 1994. The water in monitoring well 10U was frozen on January 10, 1995. Otherwise, an absence of data indicates that the monitoring wells were dry.

APPENDIX B Monitoring-well hydrographs



Hydrograph 11 Water levels at well location 7. Monitoring well 11 was installed on May 18, 1994. Otherwise, an absence of data indicates that the monitoring well was dry.



Hydrograph 12 Water levels at well location 12. Monitoring wells 12M and 12U were installed on May 18, 1994. Otherwise, an absence of data indicates that the monitoring wells were dry.

APPENDIX C Water-Level Elevations and Depths to Water Below Land Surface

Table C1 Water-level elevations referenced to NGVD, 1929 (m)

Well	11/18/92	11/19/92	12/17/92	1/8/93	2/5/93	3/5/93	4/6/93	4/29/93	6/8/93	7/8/93	7/15/93	7/20/93	10/12/93	11/4/93	12/2/93
R1a	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
1a	139.70	139.71	139.83	139.57	139.45	139.7	139.89	140.11	139.87	140.31	140.41	140.36	**	**	**
1b	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
1c	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
2a	140.48	139.77	139.95	139.65	139.49	139.76	140.04	140.27	139.98	140.41	140.48	140.48	140.07	139.55	139.54
2b	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
3a	141.36	139.75	140.04	139.68	139.54	139.80	140.20	140.48	140.07	140.69	140.79	140.76	140.09	139.57	139.56
3b	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
3c	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
4a	139.70	139.68	139.86	139.6	139.47	140.00	139.94	140.16	139.90	140.36	140.42	140.40	140.08	139.56	139.54
4b	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
4c	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
5a	139.51	139.50	139.73	139.45	139.31	139.54	139.85	140.10	139.80	140.36	140.44	140.41	139.96	139.41	139.36
5b	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
6	139.26	139.27	139.37	139.19	139.09	139.09	139.48	139.67	139.47	139.98	140.06	140.04	139.81	139.22	139.14
7a	*	*	*	*	139.2	139.38	139.54	139.69	139.53	139.90	139.99	139.97	139.84	139.33	139.24
7b	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
8a	*	*	*	*	*	139.63	139.87	140.06	139.76	140.31	140.45	140.43	140.00	139.45	139.42
8b	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
9a	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
9b	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
10a	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
10b	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
11	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
12a	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
12b	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*

* Monitoring well not yet installed

** Monitoring well destroyed

APPENDIX C Water-Level Elevations and Depths to Water Below Land Surface

Table C1 *(continued)* Water-level elevations referenced to NGVD, 1929 (m)

	1/26/94	3/10/94	4/20/94	5/16/94	5/24/94	6/16/94	7/13/94	8/1/94	9/7/94	10/1/94	10/29/94	12/2/94	1/10/95	2/4/95	3/4/95
R1a	*	*	139.59	139.68	139.54	139.38	139.42	139.29	139.25	139.34	139.36	139.41	139.37	139.64	139.39
1a	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
1b	*	*	*	*	dry	dry	dry	dry	dry	dry	dry	dry	dry	139.73	dry
1c	*	*	*	*	dry	dry	dry	dry	dry	dry	dry	dry	dry	139.88	dry
2a	139.41	139.68	139.53	139.70	139.53	139.38	139.43	139.28	139.27	139.37	139.38	139.41	139.36	139.61	139.38
2b	*	*	*	*	139.46	139.34	139.36	139.3	139.3	139.35	139.42	139.43	139.37	139.68	139.39
3a	139.53	139.75	139.56	139.76	140.58	139.41	139.46	139.34	139.03	139.43	139.42	139.44	139.39	139.62	139.41
3b	*	*	*	*	140.39	139.45	139.49	139.45	139.32	139.38	139.40	139.46	139.39	139.57	139.44
3c	*	*	*	*	dry	dry	dry	dry	dry	dry	139.94	dry	dry	dry	dry
4a	139.45	139.55	139.41	139.56	139.43	139.27	139.3	139.38	139.17	139.26	139.25	139.29	139.24	139.47	139.24
4b	*	*	*	*	139.42	139.24	139.26	dry	dry	139.26	139.25	139.29	139.25	139.52	139.27
4c	*	*	*	*	139.40	dry	dry	dry	dry	dry	dry	139.3	dry	139.57	dry
5a	139.26	139.54	139.39	139.59	139.43	139.25	139.28	139.16	139.14	139.23	139.21	139.24	139.19	139.43	139.22
5b	*	*	*	*	139.43	139.24	139.28	139.18	dry	139.23	139.21	139.24	139.19	139.43	139.22
6	139.12	139.26	139.15	139.28	139.17	139.05	139.06	139.01	139.31	139.06	139.04	139.07	139.04	139.19	139.05
7a	139.19	139.34	139.24	139.37	139.26	139.12	139.15	139.04	139.03	139.10	139.09	139.12	139.08	139.29	139.10
7b	*	*	*	*	dry	dry	dry	dry	dry	dry	dry	dry	dry	139.45	139.36
8a	139.36	139.51	139.38	139.52	139.40	139.27	139.31	139.23	139.23	139.3	139.28	139.31	139.26	139.48	139.26
8b	*	*	*	*	dry	dry	139.38	dry	dry	dry	dry	dry	139.38	139.69	139.38
9a	*	*	*	*	139.21	139.11	139.13	139.04	139.02	139.08	139.08	139.13	139.10	139.30	139.12
9U	*	*	*	*	dry	dry	dry	dry	dry	dry	dry	dry	139.39	139.43	139.39
10a	*	*	*	*	139.72	139.44	139.49	139.38	139.30	139.42	139.37	139.40	139.34	139.62	139.37
10b	*	*	*	*	139.96	dry	dry	dry	dry	dry	dry	139.96	frozen	140.02	dry
11	*	*	*	*	139.89	139.52	139.6	139.50	139.40	139.53	139.48	139.51	139.45	139.75	139.47
12a	*	*	*	*	139.77	139.48	139.53	139.42	139.33	139.45	139.39	139.42	139.37	139.64	139.40
12b	*	*	*	*	139.64	dry	139.64	dry	dry	dry	dry	140.00	139.71	140.34	139.93

* Monitoring well not yet installed

** Monitoring well destroyed

APPENDIX C Water-Level Elevations and Depths to Water Below Land Surface

Table C1 *(continued)* Water-level elevations referenced to NGVD, 1929 (m)

Well	4/1/95	4/15/95	4/29/95	5/12/95	6/14/95	6/19/95	7/24/95	8/25/95	9/22/95	10/21/95	11/21/95	12/30/95	1/27/96	2/24/96	3/14/96
R1a	139.53	139.84	139.8	139.96	139.99	139.57	139.37	139.38	139.28	139.39	139.43	139.32	139.43	139.39	139.41
1a	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
1b	dry	139.84	139.8	139.96	139.99	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry
1c	dry	139.93	dry	139.96	139.99	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry
2a	139.56	139.9	139.87	140.04	140.03	139.58	139.44	139.39	139.28	139.41	139.44	139.33	139.44	139.39	139.42
2b	139.53	139.84	139.80	139.96	140.00	139.51	139.71	139.37	139.32	139.40	139.44	139.32	139.45	139.38	139.44
3a	139.42	140.02	139.99	140.18	140.11	139.63	139.46	139.45	139.32	139.47	139.49	139.37	139.49	139.44	139.46
3b	139.55	139.77	139.92	140.09	140.25	139.86	139.49	139.50	139.37	139.41	139.55	139.37	139.49	139.50	139.47
3c	139.94	140.00	139.98	140.18	140.11	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry
4a	139.40	139.70	139.69	138.83	139.81	139.46	139.33	139.28	139.17	139.28	139.31	139.20	139.31	139.27	139.31
4b	139.42	139.75	139.72	139.88	139.85	139.49	139.44	139.29	139.19	139.30	139.34	139.22	139.34	139.29	139.31
4c	139.31	139.76	139.74	139.9	139.88	139.49	139.53	139.30	dry	139.30	139.34	dry	139.31	dry	dry
5a	139.40	139.74	139.72	139.88	139.83	139.49	139.28	139.27	139.15	139.27	139.29	139.17	139.29	139.24	139.46
5b	139.40	139.74	139.73	139.89	139.83	139.49	139.28	139.27	139.16	139.27	139.30	139.16	139.30	139.25	139.27
6	139.16	139.41	139.39	139.53	139.50	139.21	139.06	139.05	138.99	139.07	139.10	139.02	139.10	139.08	139.07
7a	139.24	139.46	139.46	139.55	139.53	139.3	139.18	139.14	139.04	139.14	139.16	139.06	139.16	139.12	139.15
7b	dry	139.46	139.44	139.56	139.59	dry	dry	dry	dry	dry	dry	dry	frozen	dry	dry
8a	139.40	139.67	139.67	139.80	139.74	139.42	139.29	139.27	139.18	139.32	139.33	139.22	139.28	139.23	139.31
8b	dry	139.49	139.46	139.60	139.55	dry	139.66	dry	dry	dry	dry	dry	dry	139.46	dry
9a	139.21	139.36	139.35	139.42	139.42	139.25	139.15	139.13	139.05	139.12	139.15	139.08	139.15	139.12	139.15
9b	dry	139.39	139.39	139.41	139.39	139.35	dry	dry	dry	dry	dry	dry	139.44	dry	dry
10a	139.64	140.15	140.15	140.38	140.30	139.86	139.44	139.47	139.31	139.46	139.48	139.29	139.46	139.40	139.41
10b	dry	140.16	140.13	140.36	140.23	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry
11	139.80	140.42	140.39	140.68	140.55	140.05	139.57	139.6	139.41	139.59	139.61	139.41	139.67	139.55	139.54
12a	139.69	140.19	140.19	140.43	140.36	139.93	139.48	139.52	139.35	139.51	139.52	139.31	139.48	139.42	139.43
12b	dry	140.13	140.10	140.22	140.06	dry	dry	dry	dry	dry	139.89	139.71	140.49	139.99	140.07

* Monitoring well not yet installed

** Monitoring well destroyed

APPENDIX C Water-Level Elevations and Depths to Water Below Land Surface

Table C1 *(continued)* Water-level elevations referenced to NGVD, 1929 (m)

Well	4/20/96	5/8/96	6/3/96	7/3/96	7/30/96	8/24/96	9/21/96	10/15/96	11/16/96	12/16/96	1/9/97	2/15/97	3/14/97	4/2/97	4/16/97
R1a	139.45	140.02	140.02	139.63	139.34	139.24	139.26	139.25	139.32	139.13	139.16	139.14	139.51	139.55	139.92
1a	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
1b	dry	139.99	140.02	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	139.90
1c	dry	139.80	140.81	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	139.69
2a	139.49	140.08	140.10	139.70	139.35	139.27	139.30	139.28	139.34	139.07	138.96	139.06	139.51	139.59	140.03
2b	139.46	139.98	140.06	139.66	clogged	clogged	dry	139.33	139.40	dry	dry	dry	139.70	139.54	139.90
3a	139.54	140.19	140.23	139.80	139.40	139.32	139.37	139.33	139.38	139.04	138.94	139.01	139.52	139.65	140.20
3b	139.55	140.02	140.31	139.84	139.48	139.35	139.33	139.40	139.44	139.22	138.18	139.16	139.56	139.63	140.10
3c	dry	140.24	140.24	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	140.20
4a	139.37	139.91	139.91	139.57	139.25	139.17	139.20	139.18	139.23	138.86	138.74	138.92	139.38	139.49	139.86
4b	139.37	139.91	139.94	139.57	139.25	139.17	139.19	139.19	139.23	dry	dry	dry	139.39	139.47	139.86
4c	139.38	139.95	139.97	139.56	dry	dry	dry	dry	dry	dry	dry	dry	139.40	139.47	139.88
5a	139.34	139.94	139.92	139.60	139.23	139.14	139.15	139.13	139.18	138.72	138.58	138.84	139.35	139.46	139.93
5b	139.34	139.95	139.95	139.62	139.24	dry	dry	dry	139.21	dry	dry	dry	139.35	139.45	139.93
6	139.11	139.56	139.52	139.27	139.04	139.00	139.22	139.02	139.05	138.77	138.68	138.83	139.15	139.16	139.51
7a	139.20	139.60	139.59	139.37	139.09	139.03	139.03	139.03	139.10	138.73	138.62	138.82	139.21	139.26	139.54
7b	dry	139.70	139.60	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	139.53
8a	139.37	139.81	139.83	139.55	139.27	139.21	139.32	139.26	139.28	138.91	138.74	138.89	139.31	139.38	139.76
8b	dry	139.75	139.59	dry	dry	dry	dry	dry	dry	dry	dry	dry	**	**	139.93
9a	139.17	139.48	139.46	139.27	139.08	139.03	139.04	139.04	139.10	138.87	138.79	138.91	139.20	139.23	139.40
9b	dry	139.58	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry
10a	139.52	139.63	140.34	139.92	139.38	139.26	139.25	139.26	139.27	138.84	138.70	138.98	139.54	***	***
10b	dry	141.18	140.36	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	***	***
11	139.69	140.66	140.69	140.19	139.53	139.37	139.35	139.37	139.38	138.96	dry	139.07	139.73	***	***
12a	139.55	140.30	140.34	139.95	139.40	139.28	139.26	139.28	139.30	138.92	138.78	139.04	139.57	***	***
12b	139.85	140.39	140.18	dry	dry	dry	dry	dry	dry	dry	dry	139.91	140.16	***	***

* Monitoring well not yet installed

** Monitoring well destroyed

*** Discontinued reading

APPENDIX C Water-Level Elevations and Depths to Water Below Land Surface

Table C1 *(continued)* Water-level elevations referenced to NGVD, 1929 (m)

Well	5/14/97	6/18/97	7/16/97	8/12/97	8/20/97	10/2/97
R1a	139.74	139.38	139.29	139.28	139.26	139.22
1a	**	**	**	**	**	**
1b	139.75	dry	dry	dry	dry	dry
1c	dry	dry	dry	dry	dry	dry
2a	139.81	139.38	139.31	139.32	139.28	139.24
2b	139.87	139.37	dry	139.35	139.34	dry
3a	139.91	139.43	139.37	139.39	139.35	139.29
3b	139.97	139.52	139.4	139.38	139.38	139.29
3c	dry	dry	dry	dry	dry	dry
4a	139.65	139.27	139.21	139.23	139.20	139.13
4b	139.66	139.28	139.22	139.21	139.20	dry
4c	139.67	dry	dry	dry	dry	dry
5a	139.67	139.24	139.19	139.20	139.17	139.10
5b	139.67	139.25	139.20	139.20	139.19	dry
6	139.34	139.08	139.04	139.06	139.06	138.99
7a	139.41	139.11	139.05	139.08	139.05	138.99
7b	dry	dry	dry	dry	dry	dry
8a	139.56	139.24	**	**	**	**
8b	**	**	**	**	**	**
9a	139.33	139.11	139.05	139.07	139.05	139.00
9b	dry	dry	dry	dry	dry	dry

* Monitoring well not yet installed
** Monitoring well destroyed
*** Discontinued reading

APPENDIX C Water-Level Elevations and Depths to Water Below Land Surface

Table C2 Water-level depth[1] below land surface (m)

Well	11/18/92	11/19/92	12/17/92	1/8/93	2/5/93	3/5/93	4/6/93	4/29/93	6/8/93	7/8/93	7/15/93	7/20/93	10/12/93	11/4/93	12/2/93
R1a	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
1a	1.07	1.06	0.94	1.20	1.32	1.07	0.88	0.66	0.90	0.46	0.36	0.41	**	**	**
1b	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
1c	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
2a	-0.61	0.10	-0.08	0.22	0.38	0.11	-0.17	-0.40	-0.11	-0.54	-0.61	-0.61	-0.20	0.32	0.33
2b	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
3a	-0.72	0.89	0.60	0.96	1.10	0.84	0.44	0.16	0.57	-0.05	-0.15	-0.12	0.55	1.07	1.08
3b	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
3c	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
4a	0.29	0.31	0.13	0.39	0.52	-0.01	0.05	-0.17	0.09	-0.37	-0.43	-0.41	-0.09	0.43	0.45
4b	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
4c	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
5a	0.96	0.97	0.74	1.02	1.16	0.93	0.62	0.37	0.67	0.11	0.03	0.06	0.51	1.06	1.11
5b	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
6	0.70	0.69	0.59	0.77	0.87	0.87	0.48	0.29	0.49	-0.02	-0.10	-0.08	0.15	0.74	0.82
7a	*	*	*	*	0.47	0.29	0.13	-0.02	0.14	-0.23	-0.32	-0.30	-0.17	0.34	0.43
7b	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
8a	*	*	*	*	*	0.21	-0.03	-0.22	0.08	-0.47	-0.61	-0.59	-0.16	0.39	0.42
8b	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
9a	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
9b	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
10a	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
10b	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
11	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
12a	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
12b	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*

[1] Negative value indicates water-level above land suface
* Monitoring well not yet installed
** Monitoring well destroyed

APPENDIX C Water-Level Elevations and Depths to Water Below Land Surface

Table C2 *(continued)* Water-level depth[1] below land surface (m)

Well	1/26/94	3/10/94	4/20/94	5/16/94	5/24/94	6/16/94	7/13/94	8/1/94	9/7/94	10/1/94	10/29/94	12/2/94	1/10/95	2/4/95	3/4/95
R1a	*	*	1.19	1.10	1.24	1.40	1.36	1.49	1.53	1.44	1.42	1.37	1.41	1.14	1.39
1a	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
1b	*	*	*	*	dry	dry	dry	dry	dry	dry	dry	dry	dry	1.07	dry
1c	*	*	*	*	dry	dry	dry	dry	dry	dry	dry	dry	dry	0.93	dry
2a	0.46	0.19	0.34	0.17	0.34	0.49	0.44	0.59	0.60	0.50	0.49	0.46	0.51	0.26	0.49
2b	*	*	*	*	0.36	0.48	0.46	0.52	0.52	0.47	0.40	0.39	0.45	0.14	0.43
3a	1.11	0.89	1.08	0.88	0.06	1.23	1.18	1.30	1.61	1.21	1.22	1.20	1.25	1.02	1.23
3b	*	*	*	*	0.23	1.17	1.13	1.17	1.30	1.24	1.22	1.16	1.23	1.05	1.18
3c	*	*	*	*	dry	dry	dry	dry	dry	dry	0.67	dry	dry	dry	dry
4a	0.54	0.44	0.58	0.43	0.56	0.72	0.69	0.61	0.82	0.73	0.74	0.70	0.75	0.52	0.75
4b	*	*	*	*	0.44	0.62	0.60	dry	dry	0.60	0.61	0.57	0.61	0.34	0.59
4c	*	*	*	*	0.45	dry	dry	dry	dry	dry	dry	0.55	dry	0.28	dry
5a	1.21	0.93	1.08	0.88	1.04	1.22	1.19	1.31	1.33	1.24	1.26	1.23	1.28	1.04	1.25
5b	*	*	*	*	1.00	1.19	1.15	1.25	dry	1.20	1.22	1.19	1.24	1.00	1.21
6	0.84	0.70	0.81	0.68	0.79	0.91	0.90	0.95	0.65	0.90	0.92	0.89	0.92	0.77	0.91
7a	0.48	0.33	0.43	0.30	0.41	0.55	0.52	0.63	0.64	0.57	0.58	0.55	0.59	0.38	0.57
7b	*	*	*	*	dry	dry	dry	dry	dry	dry	dry	dry	dry	0.25	0.34
8a	0.48	0.33	0.46	0.32	0.44	0.57	0.53	0.61	0.61	0.54	0.56	0.53	0.58	0.36	0.58
8b	*	*	*	*	dry	dry	0.27	dry	dry	dry	dry	dry	0.27	-0.04	0.27
9a	*	*	*	*	0.40	0.50	0.48	0.57	0.59	0.53	0.53	0.48	0.51	0.31	0.49
9b	*	*	*	*	dry	dry	dry	dry	dry	dry	dry	dry	0.23	0.19	0.23
10a	*	*	*	*	0.88	1.16	1.11	1.22	1.30	1.18	1.23	1.20	1.26	0.98	1.23
10b	*	*	*	*	0.65	dry	dry	dry	dry	dry	dry	0.65	frozen	0.59	dry
11	*	*	*	*	1.36	1.73	1.65	1.75	1.85	1.72	1.77	1.74	1.80	1.50	1.78
12a	*	*	*	*	0.61	0.90	0.85	0.96	1.05	0.93	0.99	0.96	1.01	0.74	0.98
12b	*	*	*	*	0.71	dry	0.71	dry	dry	dry	dry	0.35	0.64	0.01	0.42

[1] Negative value indicates water-level above land suface

* Monitoring well not yet installed

** Monitoring well destroyed

APPENDIX C Water-Level Elevations and Depths to Water Below Land Surface

Table C2 *(continued)* Water-level depth[1] below land surface (m)

Well	4/1/95	4/15/95	4/29/95	5/12/95	6/14/95	6/19/95	7/24/95	8/25/95	9/22/95	10/21/95	11/21/95	12/30/95	1/27/96	2/24/96	3/14/96
R1a	1.25	0.94	0.98	0.82	0.79	1.21	1.41	1.40	1.50	1.39	1.35	1.46	1.35	1.39	1.37
1a	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
1b	dry	0.96	1.00	0.84	0.81	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry
1c	dry	0.88	dry	0.85	0.82	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry
2a	0.31	-0.03	0.00	-0.17	-0.16	0.29	0.43	0.48	0.59	0.46	0.43	0.54	0.43	0.48	0.45
2b	0.29	-0.02	0.02	-0.14	-0.18	0.31	0.11	0.45	0.50	0.42	0.38	0.50	0.37	0.44	0.38
3a	1.22	0.62	0.65	0.46	0.53	1.01	1.18	1.19	1.32	1.17	1.15	1.27	1.15	1.20	1.18
3b	1.07	0.85	0.70	0.53	0.37	0.76	1.13	1.12	1.25	1.21	1.07	1.25	1.13	1.12	1.15
3b	0.67	0.61	0.63	0.43	0.50	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry
4a	0.59	0.29	0.30	1.16	0.18	0.53	0.66	0.71	0.82	0.71	0.68	0.79	0.68	0.72	0.68
4b	0.44	0.11	0.14	-0.02	0.01	0.37	0.42	0.57	0.67	0.56	0.52	0.64	0.52	0.57	0.55
4c	0.54	0.09	0.11	-0.05	-0.03	0.36	0.32	0.55	dry	0.55	0.51	dry	0.54	dry	dry
5a	1.07	0.73	0.75	0.59	0.64	0.98	1.19	1.20	1.32	1.20	1.18	1.30	1.18	1.23	1.01
5b	1.03	0.69	0.70	0.54	0.60	0.94	1.15	1.16	1.27	1.16	1.13	1.27	1.13	1.18	1.16
6	0.80	0.55	0.57	0.43	0.46	0.75	0.90	0.91	0.97	0.89	0.86	0.94	0.86	0.88	0.89
7a	0.43	0.21	0.21	0.12	0.14	0.37	0.49	0.53	0.63	0.53	0.51	0.61	0.51	0.55	0.52
7b	dry	0.24	0.26	0.14	0.11	dry	dry	dry	dry	dry	dry	dry	frozen	dry	dry
8a	0.44	0.17	0.17	0.04	0.10	0.42	0.55	0.57	0.66	0.52	0.51	0.62	0.56	0.61	0.53
8b	dry	0.16	0.19	0.05	0.10	dry	-0.01	dry	dry	dry	dry	dry	dry	0.19	dry
9a	0.40	0.25	0.26	0.19	0.19	0.36	0.46	0.48	0.56	0.49	0.46	0.53	0.46	0.49	0.46
9b	dry	0.23	0.23	0.21	0.23	0.27	dry	dry	dry	dry	dry	dry	0.18	dry	dry
10a	0.96	0.45	0.45	0.22	0.30	0.74	1.16	1.13	1.29	1.14	1.12	1.31	1.14	1.20	1.19
10b	dry	0.45	0.48	0.25	0.38	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry
11	1.45	0.83	0.86	0.57	0.70	1.20	1.68	1.65	1.84	1.66	1.64	1.84	1.58	1.70	1.71
12a	0.69	0.19	0.19	-0.05	0.02	0.45	0.90	0.86	1.03	0.87	0.86	1.07	0.90	0.96	0.95
12b	dry	0.22	0.25	0.13	0.29	dry	dry	dry	dry	dry	0.46	0.64	-0.14	0.36	0.28

[1] Negative value indicates water-level above land suface

* Monitoring well not yet installed

** Monitoring well destroyed

APPENDIX C Water-Level Elevations and Depths to Water Below Land Surface

Table C2 *(continued)* Water-level depth below land surface (m)

Well	4/20/96	5/8/96	6/3/96	7/3/96	7/30/96	8/24/96	9/21/96	10/15/96	11/16/96	12/16/96	1/9/97	2/15/97	3/14/97	4/2/97	4/16/97
R1a	1.33	0.76	0.76	1.15	1.44	1.54	1.52	1.53	1.46	1.65	1.62	1.64	1.27	1.23	0.86
1a	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
1b	dry	0.81	0.78	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	0.90
1c	dry	1.01	0.00	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	1.12
2a	0.38	-0.21	-0.23	0.17	0.52	0.60	0.57	0.59	0.53	0.80	0.91	0.81	0.36	0.28	-0.16
2b	0.36	-0.16	-0.24	0.16	clogged	clogged	dry	0.49	0.42	dry	dry	dry	0.12	0.28	-0.08
3a	1.10	0.45	0.41	0.84	1.24	1.32	1.27	1.31	1.26	1.60	1.70	1.63	1.12	0.99	0.44
3b	1.07	0.60	0.31	0.78	1.14	1.27	1.29	1.22	1.18	1.40	2.44	1.46	1.06	0.99	0.52
3c	dry	0.37	0.37	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	0.41
4a	0.62	0.08	0.08	0.42	0.74	0.82	0.79	0.81	0.76	1.13	1.25	1.07	0.61	0.50	0.13
4b	0.49	-0.05	-0.08	0.29	0.61	0.69	0.67	0.67	0.63	dry	dry	dry	0.47	0.39	0.00
4c	0.47	-0.10	-0.12	0.29	dry	dry	dry	dry	dry	dry	dry	dry	0.45	0.38	-0.03
5a	1.13	0.53	0.55	0.87	1.24	1.33	1.32	1.34	1.29	1.75	1.89	1.63	1.12	1.01	0.54
5b	1.09	0.48	0.48	0.81	1.19	dry	dry	dry	1.22	dry	dry	dry	1.08	0.98	0.50
6	0.85	0.40	0.44	0.69	0.92	0.96	0.74	0.94	0.91	1.19	1.28	1.13	0.81	0.80	0.45
7a	0.47	0.07	0.08	0.30	0.58	0.64	0.64	0.64	0.57	0.94	1.05	0.85	0.46	0.41	0.13
7b	dry	0.00	0.10	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	0.17
8a	0.47	0.03	0.01	0.29	0.57	0.63	0.52	0.58	0.56	0.93	1.10	0.95	0.53	0.46	0.08
8b	dry	-0.10	0.06	dry	dry	dry	dry	dry	dry	dry	dry	dry	**	**	-0.28
9a	0.44	0.13	0.15	0.34	0.53	0.58	0.57	0.57	0.51	0.74	0.82	0.70	0.41	0.38	0.21
9b	dry	0.04	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry
10a	1.08	0.97	0.26	0.68	1.22	1.34	1.35	1.34	1.33	1.76	1.90	1.62	1.06	***	***
10b	dry	-0.57	0.25	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	***	***
11	1.56	0.59	0.56	1.06	1.72	1.88	1.90	1.88	1.87	2.29	dry	2.18	1.52	***	***
12a	0.83	0.08	0.04	0.43	0.98	1.10	1.12	1.10	1.08	1.46	1.60	1.34	0.81	***	***
12b	0.50	-0.04	0.17	dry	dry	dry	dry	dry	dry	dry	dry	0.44	0.19	***	***

[1] Negative value indicates water-level above land surface
* Monitoring well not yet installed
** Monitoring well destroyed
*** Discontinued reading

APPENDIX C Water-Level Elevations and Depths to Water Below Land Surface

Table C2 *(continued)* Water-level depth below land surface (m)

Well	5/14/97	6/18/97	7/16/97	8/12/97	8/20/97	10/2/97
R1a	1.04	1.40	1.49	1.50	1.52	1.56
1a	**	**	**	**	**	**
1b	1.05	dry	dry	dry	dry	dry
1c	dry	dry	dry	dry	dry	dry
2a	0.06	0.49	0.56	0.55	0.59	0.63
2b	-0.05	0.45	dry	0.47	0.48	dry
3a	0.73	1.21	1.27	1.25	1.29	1.35
3b	0.65	1.10	1.22	1.24	1.24	1.33
3c	dry	dry	dry	dry	dry	dry
4a	0.34	0.72	0.78	0.76	0.79	0.86
4b	0.20	0.58	0.64	0.65	0.66	dry
4c	0.18	dry	dry	dry	dry	dry
5a	0.80	1.23	1.28	1.27	1.30	1.37
5b	0.76	1.18	1.23	1.23	1.24	dry
6	0.62	0.88	0.92	0.90	0.90	0.97
7a	0.26	0.56	0.62	0.59	0.62	0.68
7b	dry	dry	dry	dry	dry	dry
8a	0.28	0.60	**	**	**	**
8b	**	**	**	**	**	**
9a	0.28	0.50	0.56	0.54	0.56	0.61
9b	dry	dry	dry	dry	dry	dry

APPENDIX C Water-Level Elevations and Depths to Water Below Land Surface

Table C3 Water-level elevations referenced to NGVD, 1929 (m)

Stage Gage	1	2	3	4	5
11/18/92	*	*	*	*	*
11/19/92	*	*	*	*	*
12/17/92	138.49	*	*	*	*
1/8/93	138.42	*	*	*	*
2/5/93	138.38	*	*	*	*
3/5/93	138.40	*	*	*	*
4/6/93	138.54	*	*	*	*
4/29/93	138.78	*	*	*	*
6/8/93	138.86	*	*	*	*
7/8/93	139.27	*	*	*	*
7/15/93	139.39	*	*	*	*
7/20/93	139.39	*	*	*	*
10/12/93	139.68	*	*	*	*
11/4/93	138.89	*	*	*	*
12/2/93	139.19	139.09	dry	*	*
1/26/94	138.28	139.06	dry	*	*
3/10/94	138.69	139.13	dry	*	*
4/20/94	138.32	139.05	dry	*	*
5/16/94	138.40	139.09	dry	*	*
5/24/94	138.37	139.03	dry	139.48	138.65
6/16/94	138.33	138.98	dry	139.30	138.61
7/13/94	138.29	138.99	dry	**	138.61
8/1/94	138.29	138.99	dry	**	138.66
9/7/94	138.27	139.00	dry	**	138.67
10/1/94	138.29	139.03	dry	**	138.72
10/29/94	138.28	139.02	dry	**	138.71
12/2/94	138.30	139.04	dry	**	138.73
1/10/95	138.26	139.10	snow	**	138.63
2/4/95	138.31	139.04	139.61	**	138.67
3/4/95	138.26	138.98	dry	**	dry
4/1/95	138.33	139.05	139.53	**	138.68
4/15/95	138.47	139.17	139.83	**	138.87
4/29/95	138.45	139.17	139.78	**	138.85
5/12/95	138.56	139.25	139.95	**	138.97
6/14/95	138.57	139.23	139.99	**	138.91
6/19/95	138.41	139.06	139.59	**	138.71
7/24/95	138.37	139.00	139.57	**	138.70
8/25/95	138.37	138.99	dry	**	138.69
9/22/95	138.31	138.97	dry	**	138.60
10/21/95	138.34	139.07	dry	**	138.61
11/21/95	138.33	139.12	dry	**	138.61
12/30/95	138.27	139.05	dry	**	138.61
1/27/96	138.33	139.06	139.65	**	138.64
2/24/96	138.29	139.03	dry	**	138.61
3/14/96	***	139.02	dry	**	138.62
4/20/96	138.35	139.02	dry	**	138.96
5/8/96	138.59	139.22	139.90	**	138.95
6/3/96	138.64	139.25	140.02	**	138.99
7/3/96	138.57	139.10	139.65	**	138.83
7/30/96	138.41	138.99	dry	**	139.14
8/24/96	138.35	138.97	dry	**	139.07
9/21/96	138.30	139.25	dry	**	***
10/15/96	138.32	139.12	dry	**	**
11/16/96	138.30	139.22	dry	**	**
12/16/96	138.27	***	dry	**	**

* Stage gage not yet installed.
** Stage gage destroyed
*** Stage gage not read

APPENDIX C Water-Level Elevations and Depths to Water Below Land Surface

Table C3 *(continued)* Water-level elevations referenced to NGVD, 1929 (m)

	1	2	3	4	5
1/9/97	138.24	***	dry	**	**
2/15/97	138.23	***	dry	**	**
3/14/97	138.33	***	139.67	**	**
4/2/97	138.33	139.21	dry	**	**
4/16/97	138.52	139.28	139.87	**	**
5/14/97	138.41	139.20	139.81	**	**
6/18/97	138.38	139.05	dry	**	**
7/16/97	138.39	138.98	dry	**	**
8/12/97	138.43	139.01	dry	**	**
8/20/97	138.41	138.99	dry	**	**
10/2/97	138.36	138.99	dry	**	**

* Stage gage not yet installed.
** Stage gage destroyed
*** Stage gage not read

APPENDIX D Construction Information for Monitoring Wells

Table D1 Construction information for monitoring wells

Well	R1a	1a	1b	1c	2a	2b	3a	3b	3c	4a	4b	4c	5a
Elevation of top of well	141.13	141.49	140.93	141.75	140.48	141.15	141.36	140.93	141.75	140.7	140.76	141.1	141.05
Land surface elevation	140.77	140.78	140.80	140.81	139.87	139.82	140.63	140.61	140.60	139.98	139.86	139.85	140.47
Total length of pipe	2.29	3.35	1.29	1.96	4.42	1.94	4.57	1.87	1.90	6.04	1.70	1.90	3.38
Height of measuring point above land surface	0.36	0.71	0.13	0.94	0.61	1.33	0.73	0.32	1.15	0.72	0.90	1.25	0.58
Screen length	0.76	0.76	0.07	0.36	0.76	0.34	1.52	0.23	0.31	0.76	0.09	0.30	0.76
Sample length	1.93	1.73	1.15	1.02	4.01	0.60	3.05	1.56	0.75	4.14	0.81	0.65	1.65
Depth of well point	1.93	2.64	1.16	1.02	3.81	0.61	3.84	1.55	0.75	5.32	0.80	0.65	2.80
Depth to top of sand pack	0.86	1.68	1.03	0.40	2.52	0.20	1.32	0.94	0.37	1.02	0.63	0.23	1.37
Depth to top of well screen	1.17	1.79	1.04	0.62	2.96	0.24	2.23	1.26	0.44	4.47	0.68	0.31	1.95
Depth to bottom of well screen	1.93	2.55	1.11	0.98	3.72	0.58	3.75	1.49	0.75	5.23	0.77	0.61	2.71
Screened unit	lower	lower	middle	upper	lower	middle	lower	middle	upper	lower	middle	upper	lower

Table D1 *continued*

Well	5b	6a	7a	7b	8a	8b	9a	9b	10a	10b	11	12a	12b
Elevation of top of well	140.83	140.72	140.77	141.03	140.79	141.04	140.51	141.04	140.78	141.65	142.36	141.68	141.32
Land surface elevation	140.43	139.96	139.67	139.70	139.84	139.65	139.61	139.62	140.60	140.61	141.25	140.38	140.35
Total length of pipe	1.78	3.20	3.63	1.70	3.02	1.75	2.33	1.74	2.30	1.78	3.88	3.88	1.77
Height of measuring point above land surface	0.40	0.76	1.10	1.33	0.95	1.39	0.90	1.42	0.18	1.04	1.11	1.3	0.97
Screen length	0.14	0.76	0.27	0.10	0.82	0.14	0.71	0.10	0.72	0.15	0.70	0.71	0.15
Sample length	1.38	0.69	0.61	0.37	1.83	0.36	1.43	0.31	2.12	0.74	2.72	2.58	0.8
Depth of well point	1.38	2.44	2.53	0.37	2.07	0.36	1.43	0.32	2.12	0.74	2.77	2.58	0.8
Depth to top of sand pack	0.82	1.37	0.15	0.17	0.76	0.21	0.55	0.05	1.12	0.46	1.31	1.69	0.47
Depth to top of well screen	1.18	1.59	2.26	0.23	1.25	0.18	0.67	0.17	1.34	0.55	2.00	1.796	0.613
Depth to bottom of well screen	1.32	2.35	2.53	0.33	2.07	0.32	1.38	0.27	2.06	0.70	2.70	2.506	0.763
Screened unit	middle	lower	lower	middle	lower	middle	lower	middle	lower	middle	lower	lower	middle